

# The Role of Inventory Adjustments in Quantifying Factors Causing Food Price Inflation

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## Abstract

The food commodity price increases beginning in 2001 and culminating in the food crisis of 2007/08 reflected a combination of several factors, including economic growth, biofuel expansion, exchange rate fluctuations, and energy price inflation. To quantify these influences, the authors developed an empirical model that also included crop inventory adjustments. The study shows that, if inventory effects are not taken into account, the impacts of the various factors on food commodity price inflation would be overestimated. If the analysis ignores crop inventory adjustments, it indicates that prices of corn, soybean, rapeseed, rice, and wheat would have

been, respectively, 42, 38, 52, and 45 percent lower than the corresponding observed prices in 2007. If inventories are properly taken into account, the contributions of the above mentioned factors to those commodity prices are 36, 26, 26, and 35 percent, respectively. Those four factors, taken together, explain 70 percent of the price increase for corn, 55 percent for soybean, 54 percent for wheat, and 47 percent for rice during the 2001–2007 period. Other factors, such as speculation, trade policy, and weather shocks, which are not included in the analysis, might be responsible for the remaining contribution to the food commodity price increases.

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# The Role of Inventory Adjustments in Quantifying Factors Causing Food Price Inflation\*

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# 1. Introduction

Food and fuel commodity prices, which had been rising since 2001 (see Figures 1 and 2), reached record levels by mid-2008 [21, 52, 65]. According to the International Monetary Fund (IMF) primary commodity price database, world food commodity prices increased 100% or more from 2001 to 2008 (in 2005 US \$), with prices increasing by almost 300% for rice (see table inset in Figure 2).

The period between 2001 and 2008 was also the period during which production of biofuels such as ethanol and biodiesel produced from food crops grew several fold. During this time, global ethanol production from maize and sugarcane more than doubled from 30 billion liters to 65 billion liters, while biodiesel production from edible oil seeds such as soybean, oil palm, and rapeseed expanded six fold from 2 billion liters to 12 billion liters [46]. The increase in biofuel demand, which was concentrated in the United States and the European Union (EU), was primarily a response to government mandates and subsidies.<sup>1</sup> This has led to the popular opinion that biofuel policies in the high-income countries are one of the principal causes for the inflation in food commodity prices.

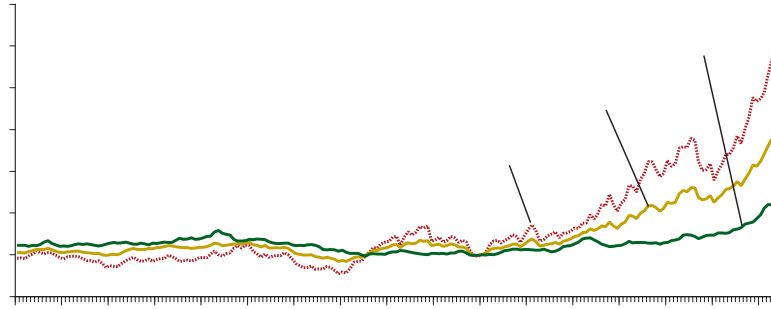
Biofuels reduce demand for oil and increase demand for agricultural goods.<sup>2</sup> With crops comprising a small share of the final cost of food in high-income countries, the impact of biofuels on food consumers is small. To low-income countries, where expenditure on raw grains and vegetable oils comprises a much larger share of the household food budget, a given increase in crop prices will have a much larger impact on food consumers.

This paper aims to identify the main factors affecting food commodity prices, and to also quantify the contributions of these factors. A distinguishing feature of our analysis is taking into account adjustments in inventories of agricultural goods in response to these various factors. Although conceptually an important component of food commodity markets, to the best of our knowledge, it is not explicitly incorporated into existing empirical/computational models.

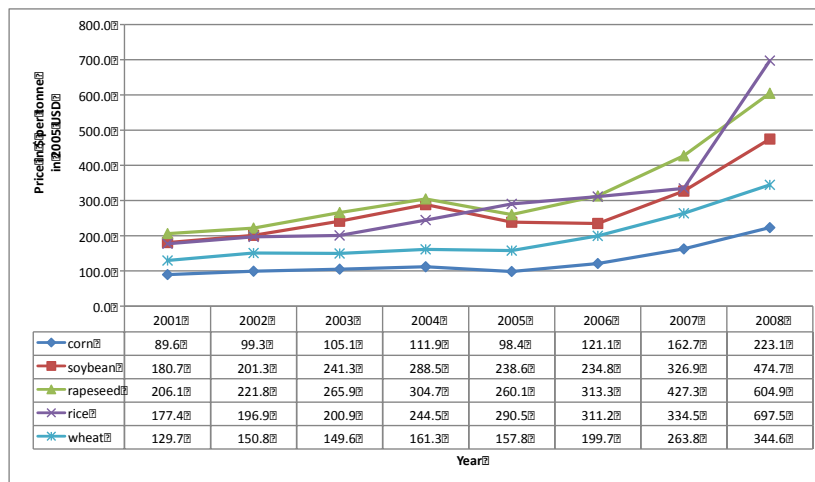
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<sup>1</sup>Growth in domestic biofuel demand in Brazil, a large biofuel producer, also increased, but was less significant relative to growth in demand in the U.S. and EU countries.

<sup>2</sup>Biofuels reduce the Organization of Petroleum Exporting Countries' (OPEC) market power, and therefore reduce energy prices [32,33].



**Figure 1. Commodity price trends (Source: [65])**



**Figure 2. Crop price trends**

Inventory levels, and their relation to consumption as captured by stock to use, played an important role in the 2007/08 food commodity spike. By 2008, the stock-to-use ratio declined to historical lows, as did inventory levels. This was the outcome of successive years of consumption exceeding production, which can be traced all the way back to 1985 [66]. The decline in inventory to historical lows resulted in commodity prices being more sensitive to any given shock.

Along with biofuel expansion, the period between 2001 and 2007 also witnessed high global economic growth, energy price inflation, and exchange rate fluctuations, among other factors. These factors also can contribute to food price increases. The rapid economic growth resulted in increased demand for meat products, which, on per calorie delivered basis, are more grain intensive than nonmeat products. Other demand side factors included expansion of biofuels and population growth, as well as speculative activity [59]. On the supply side, some of the major factors included bad weather in key grain-producing regions (especially wheat-growing regions such as the United States and EU) and increase in production costs (due to high energy prices – [60]). When extending the empirical period investigated, the supply factors would also

include stagnation of productivity growth due to cumulative underinvestment in agricultural research and technology, as well as infrastructure such as irrigation [5, 10]. All these supply factors resulted in slow or negative growth in production [2, 3, 21, 66]. Some factors affect both demand and supply. These factors include trade policies such as export bans on grains (especially the ban on rice exports by several countries in Asia, such as Bangladesh, Vietnam, and India [23])<sup>3</sup> and import tariffs on non-grain biofuels (especially the U.S. import tariffs on cane ethanol from Brazil, but also on rice in Indonesia [64]). The depreciation of the U.S. dollar relative to major world currencies has also been a contributing factor to commodity price increases [2,59], as were energy prices [33].

The rest of the report is structured as follows. In section 2, we present a review of the literature on recent increase in food commodity prices and the effect of biofuels on food commodity prices. We briefly survey historical trends in section 3. Following this, the effect of introducing an empirical model of inventory into the partial equilibrium model is also illustrated in section 4. In section 5 we extend the partial-equilibrium analysis to a multi-market multi-region framework. Section 6 describes the results from the numerical simulation of the multi-market model. This section demonstrates the importance of understanding the market for inventory to better predict the effect of any large supply or demand shock on commodity prices. Section 7 concludes the report.

## 2. Literature review

Economic equilibrium models have a long tradition of use for predicting the effects of one or more policies on prices, welfare, and a variety of other economic variables [19]. These models can be classified as partial and general equilibrium models. Partial equilibrium models are essentially the aggregation of supply and demand equations that represent economic behavior of agents in one or more markets of interest. Examples of prominent partial equilibrium models include IMPACT, AGLINK/COSIMO, FAPRI, and FASOM. <sup>4</sup>

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is a partial-equilibrium model that has often been used by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand, and food security to 2020 and beyond. Using this model, Msangi et al. simulate the impact of biofuel under different scenarios on the price of food in different regions [48]. In one of the scenarios,

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<sup>3</sup>For a comprehensive list, see the Food and Agriculture Organization's (FAO) summary on policy measures taken by governments to reduce the impact of soaring prices <http://www.fao.org/giews/english/policy/2.htm>. Also see <ftp://ftp.fao.org/docrep/fao/012/i0854e/i0854e04.pdf>

which focused on rapid global growth in biofuel production under conventional conversion technologies, the price increase for major crops ranges between 30% and 76% by 2020. There is significant increase in malnutrition in many developing country regions with Sub-Saharan Africa being the hardest hit. Using the AGLINK and COSIMO models, the OECD predicts the impact of achieving the stated policy targets (as of 2006) for biofuels in several countries [42]. It finds that compared to a situation with unchanged biofuel quantities at their 2004 levels, crop prices could increase by between 2% in the case of oilseeds and almost 60% in the case of sugar by the year 2014.

Partial models have several limitations, such as lack of acknowledgement of the finiteness of resources such as land, labor, and capital; no explicit budget constraint on households; and no check on conceptual and computation consistency of the model [30]. These limitations can be overcome by using a general equilibrium approach. Computable general equilibrium (CGE) modeling is a numerical technique that combines the theoretical framework of Walrasian general equilibrium formalized by Arrow and Debreu [6] with real world economic data to determine the levels of supply, demand, and price that support equilibrium across a specified set of markets [69]. These models, which were initially developed to analyze the impact of changes in trade policies and public finance, have subsequently found wide application in the analysis of relationship between energy and the macro economy, the impact of greenhouse gas policies, and most recently in the context of biofuel policies [10, 13, 31]. GTAP, LINKAGE, and USAGE are some prominent general equilibrium models that were used to analyze biofuels.<sup>4</sup>

Dixon, Osborne, and Rimmer [18] use a dynamic CGE model called USAGE to quantify the economy wide effects of partial replacement of crude petroleum with biofuels in the United States. They forecast the impact of the current biofuel policies on the U.S. economy in 2020 [18]. Although there is no direct discussion of the impact of these policies on the global price of food, the model predicts a reduction in agricultural exports and an increase in the export prices. Gohin and Moschini assess the impacts of the European indicative biofuel policy on the EU farm sector with a farm-detailed CGE model and predict positive income effects on farmers in the EU [26]. Birur, Hertel, and Tyner use the GTAP-E model to study the impact of six drivers of the biofuel boom, namely, the hike in crude oil prices, replacement of methyl tertiary butyl ether (MTBE) by ethanol as a gasoline additive in the United States, and subsidies for ethanol

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<sup>4</sup> *GTAP – model developed at Purdue University; LINKAGE – The World Bank’s model, and USAGE – model developed at Monash University, Australia.*

and biodiesel in the United States and EU [12]. They find that between 2001 and 2006 these drivers were responsible for a 9% increase in the price of U.S. coarse grains, 10% increase in price of oilseeds in the EU-27 region, and 11% for sugarcane in Brazil. Similar impacts were observed on energy-exporting countries in Latin America and Sub-Saharan Africa. The main drawbacks of a CGE model are the large data requirements and the high degree of complexity.

The food crisis of 2007-08 has spawned a large body of literature examining the causes for the spike in food commodity prices. Interest in the food crisis can be motivated by the impact of an increase in food commodity prices on food-insecure and poor households, which is substantial [67]. De Hoyos and Medvedev use domestic food consumer price data to show that the 5.6% increase in average food commodity price between January 2005 and December 2007 implied a 1.7 percentage point increase in the extreme poverty headcount at the global level, with significant regional variation [16] (see also Ivanic and Martin [39]). Nearly all of the increase in extreme poverty is reported to occur in South Asia and Sub-Saharan Africa. Furthermore, Regmi et al. show that when faced with higher food commodity prices, the poor switch to foods that have lower nutritional value and lack important micronutrients [57].

Although the IMF Global Food Index during the 12 months preceding March 2008 increased 43%, the U.S. food Consumer Price Index increased only 4.5%. The global food price index assigns greater weight to raw grains unlike the U.S. food Consumer Price Index where the basket places greater weight on processed foods. The reason for the smaller increase in food commodity prices is that Americans tend to consume highly processed foods. When U.S. consumers purchase foods from supermarkets, convenience stores, or restaurants, a large fraction goes to cover labor associated with preparing, serving, and marketing the food.<sup>5</sup> Similar patterns are observed in other developed countries. This is not the case in developing countries. The poor spend a larger fraction of their income on food, whereas the typical American spends slightly less than 14% of total expenditures on food.<sup>6</sup> In contrast, Africans spend 43% of their expenditures on food,<sup>7</sup> and those subsisting on less than one dollar per day in Sub-Saharan Africa may dedicate as much as 70% of their expenditures to food.<sup>8</sup>

We need a statement that the global food index assigns greater weight to raw grains unlike the U.S. CPI where the basket is processed foods. And we should refer to rich nations in general

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<sup>5</sup>USDA, <http://www.ers.usda.gov/Data/FarmToConsumer/Data/marketingbilltable1.htm>

<sup>6</sup>U.S. Department of Labor, Bureau of Labor Statistics, *Consumer Expenditure Survey*, 2006.

<ftp://ftp.bls.gov/pub/special.requests/ce/share/2006/income.txt>. Typical American refers to an individual at the median income level.

<sup>7</sup>Federal Reserve Board Staff calculation, IMF, and World Bank.

<sup>8</sup>The International Food Policy Research Institute 2020 Discussion Paper No. 43, "The World's Most Deprived."



rather than just the U.S.

Global (food) commodity price inflation equaled 43% during the 12 months ending on March, 2008. While this rate is high, it is not unprecedented. Similar increases in (food) commodity prices were observed between 1971 and 1974 and between 1994 and 1996 [52]. While biofuels were unique to the recent crisis, other (important) factors were common to one or both crises. Furthermore, each of the three periods of peak prices has been marked by a below-normal ratio of stocks to use. An IMF report assessing the impact of rise in food and fuel price on macroeconomic indicators such as balance of payments, overall inflation, and poverty also concludes that biofuels are one among several factors, which coincided to cause the food commodity price inflation [38]. This report also contends that restrictive trade policies were the major reason for the run-up in the price of rice.

**Table 1. Quantitative estimates of impact of biofuel on food commodity prices**

| <b>Source</b>          | <b>Estimate</b> | <b>Commodity</b>  | <b>Time period</b>   |
|------------------------|-----------------|-------------------|----------------------|
| Mitchell [47]          | 75%             | global food index | Jan 2002 to Feb 2008 |
| IFPRI [59]             | 39%             | corn              | 2000 to 2007         |
|                        | 21-22%          | rice and wheat    | 2000 to 2007         |
| OECD-FAO [51]          | 42%             | coarse grains     | 2008 to 2017         |
|                        | 34%             | vegetable oils    | 2008 to 2017         |
|                        | 24%             | wheat             | 2008 to 2017         |
| Collins [15]           | 25-60%          | corn              | 2006 to 2008         |
|                        | 19-26%          | U.S. retail food  | 2006 to 2008         |
| Glauber [25]           | 23-31%          | commodities       | Apr 2007 to Apr 2008 |
|                        | 10%             | global food index | Apr 2007 to Apr 2008 |
|                        | 4-5%            | U.S. retail food  | Jan to April 2008    |
| CEA [42]               | 35%             | corn              | Mar 2007 to Mar 2008 |
|                        | 3%              | global food index | Mar 2007 to Mar 2008 |
| Rajagopal et al. [54]  | 15-28%          | global corn price | 2007 to 2008         |
|                        | 10-20%          | global soy price  | 2007 to 2008         |
| Hoyos and Medvedev[16] | 6%              | global food index | 2005 to 2007         |

Abbott, Hurt, and Tyner, through a review of several reports on the food crisis, conclude that there are several key drivers of food commodity price increases: the depreciation of the dollar, global changes in production such as weather shocks, changes in patterns of food consumption, and the role of biofuels in commodity price increases [2]. They do not, however, present quantitative estimates of percentage contribution to the total price rise that is attributable to a specific factor such as biofuel consumption. The FAO in its State of Food and Agriculture 2008 Report also states that growing demand for biofuels is only among several factors driving

increases in agricultural commodity prices [21]. A USDA report describing the factors leading to the food commodity price rise concludes that the run- up in commodity price reflects a trend of slower growth in production and more rapid growth in demand that led to a tightening of world balances of grains and oilseeds over the last decade [66].

Biofuels are considered to be one among several demand-side and supply-side factors responsible for the increase in crop and food commodity prices in recent years [15, 21, 25, 43, 47, 51, 59]. Quantitative estimates of the impact of biofuels on grain prices range from 20% to 60% (see Table 1). The most pessimistic estimate ascribed 70 to 75% of the price rise between 2002 and 2008 to biofuels [47]. This report uses historical data to estimate the elasticity of world prices of agricultural commodities with respect to the price of energy and related inputs to agriculture and with respect to changes in the value of the dollar. Using these elasticities, this report estimates that between 2002 and 2007, higher prices of energy increased export prices of major U.S. food commodities by about 15 to 20 percentage points, and the depreciating dollar increased food commodity prices by about 20 percentage points. These together, it is argued, translate into a 25 to 30% increase in total price. The author argues that depletion of stocks, shifting for food cropland for production of energy crops, government response in the form of food export bans, and speculative activity, which caused prices to rise, were the consequences of the shocks considered with demand for biofuels being the main cause.

Rosegrant estimates the effect of biofuels using a simulation-based approach [59]. He simulates the market equilibrium under two different scenarios, one without high growth in biofuel and another with high growth in biofuel. For the former, he simulates a scenario in which biofuel grows at a rate which was observed between 1990 and 2000. This is the period before the rapid takeoff in demand for bioethanol. For the latter, he simulates actual demand for food crops as a feedstock for biofuel, from the years 2001 through 2007. Based on these simulations, he estimates that weighted average grain price increased by an additional 30% under the high biofuel scenario, i.e., the actual situation. The increase was highest for maize (39%) and lower for wheat and rice (22% and 21%, respectively). Using a similar approach, Rajagopal et al. estimate that U.S. ethanol production in 2007 may have been responsible for a 15% to 28% increase in the world price of maize and 10% to 20% increase in the world price of soy [54].

Global estimates of both the increase in food commodity prices and the contribution of biofuels to this increase hide variations at the regional level. Mabison and Weatherspoon argue that in South Africa food is processed and then transported several miles before it reaches the

consumer [44]. Thus, a large percentage of the price of food is a result of high fuel costs, which may not be true in other regions in the world. Increase in energy prices was therefore a major contributor to the increase in food commodity price in those regions. Yang, Zhou, and Liu argue that the current level of bioethanol production in China, which consumed 3.54% of total maize production of the country, reduced market availability of maize for other uses by about 6%. It is projected that depending on the types of feedstock, 5 to 10% of the total cultivated land in China would need to be devoted to meet the biofuel production target of 12 million metric tons for the year 2020 [70]. The associated water requirement would amount to 3272  $km^3$  per year, approximately equivalent to the annual discharge of the Yellow River. The net contribution of biofuel to the national energy pool could be limited due to generally low net energy return of conventional feedstocks. The current biofuel development paths could pose significant impacts on China's food supply, trade, and therefore food commodity prices (see also [56]). The impact of India's biofuel program, if successful, on food and water supply is also likely to be minimal as its policies intend to promote the cultivation of a non-edible and drought-tolerant biofuel crops such as *Jatropha curcas* on nonagricultural land [53].

Data also show that wheat and rice crops, which have not been utilized to a significant extent as biofuels, are the crops that recorded the highest percentage increase in price in recent years (refer to Figures 4(a), 4(b), and 4(c)). This clearly suggests that in addition to being region specific, the analyses need to be crop specific. Goldemberg and Guardabassi show that impact on food commodity prices is minimal in the case of ethanol produced from sugarcane in Brazil, which is cheaper and less intensive in inputs such as land, water, fertilizer and energy compared to corn and biodiesel [27].

Recent papers highlighted the food commodity price increases as one among several key negative impacts of first-generation biofuels [40, 41, 55]. These papers argue that some of these environmental and societal costs may be ameliorated or reversed with the development and use of next-generation biofuel feedstocks, especially cellulosic biomass from different types of wastes (agricultural, forestry, and municipal) and energy grasses such as switchgrass and *Miscanthus*. Certain types of biofuels do represent potential sources of alternative energy, but their use needs to be tempered with a comprehensive assessment of their environmental impacts. When evaluating the causes of food commodity price spikes, not only regional differences should be modeled, but also technological differences. Moreover, policy and differences in policy among nations should also be addressed.

Historically, agricultural commodity prices were low, and markets were characterized by

excess supply [24]. A recent spike in energy prices challenged this. Globalization, accompanied by capital flows, led to increase in energy demand and made biofuel a viable alternative [35, 36]. These changes challenge existing policy, as well as the (poor) response by policy practitioners in developing countries to the 2007-08 food crisis. To this end, farm support in higher income countries is a testament to the fundamental social economic and political importance of agriculture, and it leads to a very different set of issues with respect to the fuel-versus-food debate. Baka and Roland-Holst argue that the advent of biofuels offers a new opportunity for agriculture to contribute to society in Europe, and do so in a way that reduces trade rivalry and improves energy security [8]. Holding current agricultural production constant, they find that the EU has the potential to reduce oil imports between 6% and 28% by converting eligible agricultural crops into biofuels under two differing conversion scenarios.

During the 2007-08 food crisis, many countries took steps to try to minimize the effects of higher prices on their populations. Argentina, Bolivia, Cambodia, China, Egypt, Ethiopia, India, Indonesia, Kazakhstan, Mexico, Morocco, Russia, Thailand, Ukraine, Venezuela, and Vietnam are among those that have taken the easy option of restricting food exports, setting limits on food commodity prices, or both. For example, China has banned rice and maize exports; India has banned exports of rice and milk powder; Bolivia has banned the export of soy oil to Chile, Colombia, Cuba, Ecuador, Peru, and Venezuela; and Ethiopia has banned exports of major cereals. These policies contributed to the severity of the food crisis and caused contraction of the global food markets. Other nations, however, have contributed to the expansion of the global food market. Some net food-importing developing countries reduced import barriers. Morocco, for instance, cut tariffs on wheat imports from 130% to 2.5%; Nigeria cut its rice import tax from 100% to just 2.7% [67]. Although tariff reductions, in theory, may contribute to the increase in world food prices, it does reduce domestic prices in those countries.

Differences in institutions and the competitive setup lead to differences in regulation of agricultural biotechnology, where the regulatory framework ranges from promotional to preventive, and subsequently to differences in the rate of innovation [34]. These differences also lead to differences among nations in utilization of agricultural biotechnology. Although agricultural biotechnology introduces an indirect effect on yield by reducing crop losses and improved control of damage and diseases, and therefore contributes to food security, political economic considerations prevent its adoption on a global scale [28, 29, 34, 49].

Another emerging line of research uses a time-series tool to investigate the links between the

prices of various commodities. Serra et al. [61] used nonlinear time-series models to assess the price relationship within the U.S. ethanol industry. They used daily data on ethanol corn and crude oil prices and identified equilibrium relationships between these prices. They found that when corn prices are high relative to fuel prices, ethanol prices are mostly affected by the price of corn. When the price of corn is low relative to the price of fuel, then ethanol prices are likely to follow the price of fuel. Similarly, Balcombe and Rapsomanikis [9] established a consistent long-term equilibrium between ethanol prices and the price of sugarcane and oil using data from Brazil.

In summary, the literature suggests that one has to contend with several factors in order to explain the causes for the food crisis. On the demand side, another major factor is rapid economic growth in emerging economies, which increased demand for meat, a highly grain-intensive product. On the supply side, bad weather in key grain-producing regions (especially wheat-growing regions such as Australia), stagnation of productivity growth (due to underinvestment in agricultural research and technology and infrastructure such as irrigation), and increase in production costs (due to high energy prices) have resulted in slow or negative growth in production. Prices spiraled even further as a result of policies such as export bans on grains and import tariffs on non-grain biofuels (especially the U.S. import tariffs on cane ethanol from Brazil) and on account of speculative activity in reaction to such policies. Lastly, the depreciation of the U.S. dollar relative to major world currencies has also been a contributing factor to commodity price increases. Historically, when the dollar is weak, commodity prices tend to be higher and, when the dollar is strong, commodity prices tend to be lower. However, with different countries adopting different policies toward biofuels and trade, assessing the country-level impacts of these factors require case-by-case analysis.

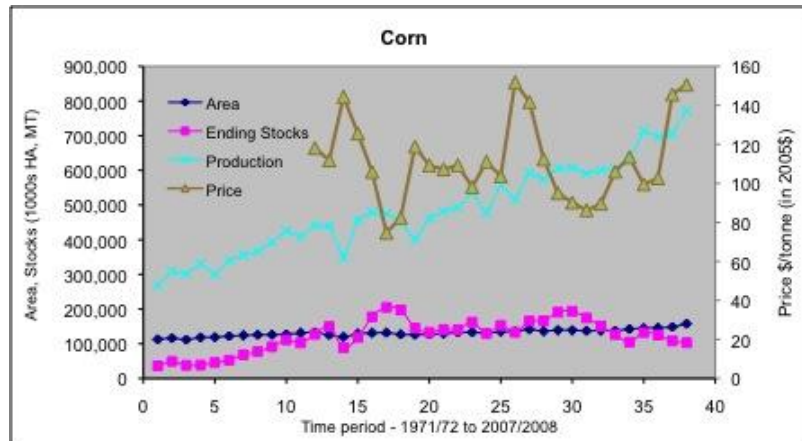
With several such factors at play, identifying the contribution of any one factor such as biofuel is a challenging task. The estimates of the impact of biofuels that can be found in the literature are wide ranging, ranging between 3% and 75%. One reason why the optimistic estimates may be an underestimate is because of a lack of representation of the market for inventory. We are not aware of any standard equilibrium models including those mentioned earlier that incorporate an explicit representation of the market for inventory.

### **3. Historical trends**

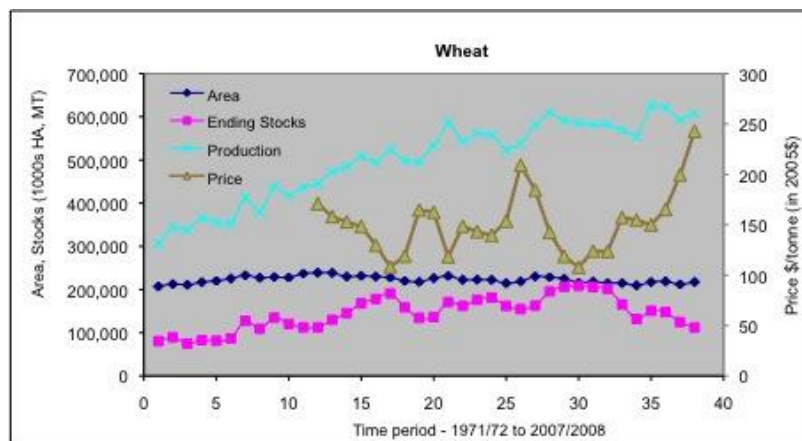
Historical trends in production, consumption, inventory, and price at the global level for four major crops, namely, maize, wheat, rice, and soybeans, are shown in figures 3(a), 3(b), 3(c),

and 3(d), respectively.<sup>9</sup> It can be seen that crop prices are countercyclical to inventory levels. In years that prices increased the level of inventory declined and vice versa.

[Historical data for maize]

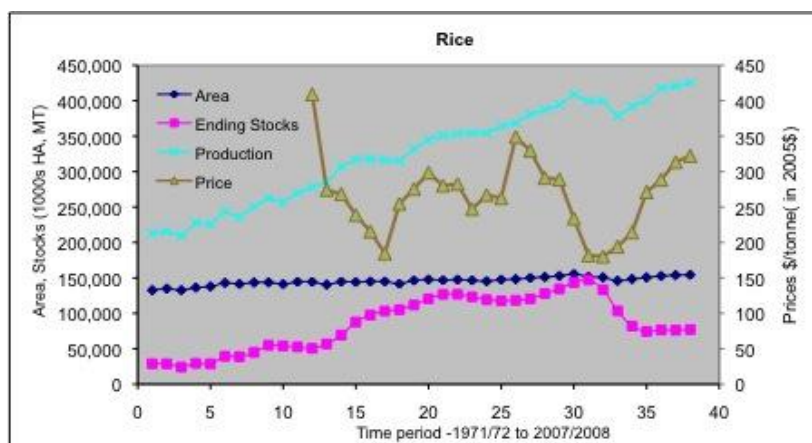


[Historical data for wheat]

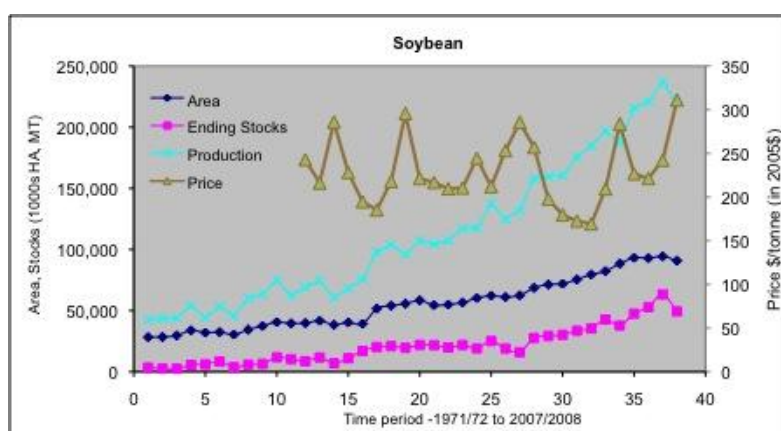


[Historical data for rice]

<sup>9</sup> Data on inventory levels were obtained from the U.S. Department of Agriculture's PSD database, while the data on the international price were obtained from the IMF price database on prices of primary commodities (available online at <http://www.fas.usda.gov/psdonline/> and <http://www.imf.org/external/np/res/commod/index.asp>, respectively). Price data were not available for the years prior to 1980 and, hence, are not shown.



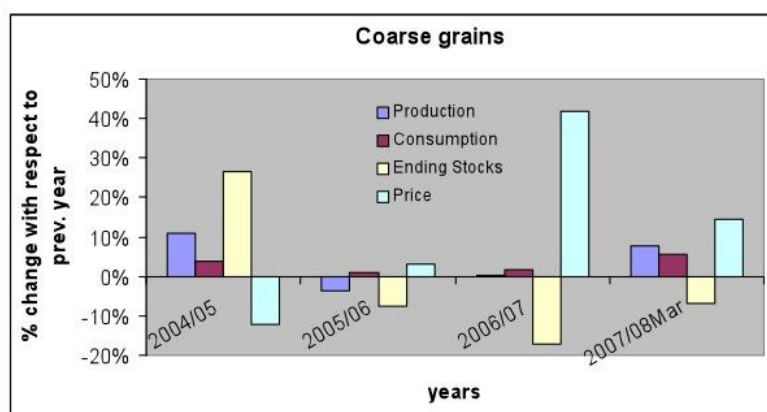
[Historical data for soybean]



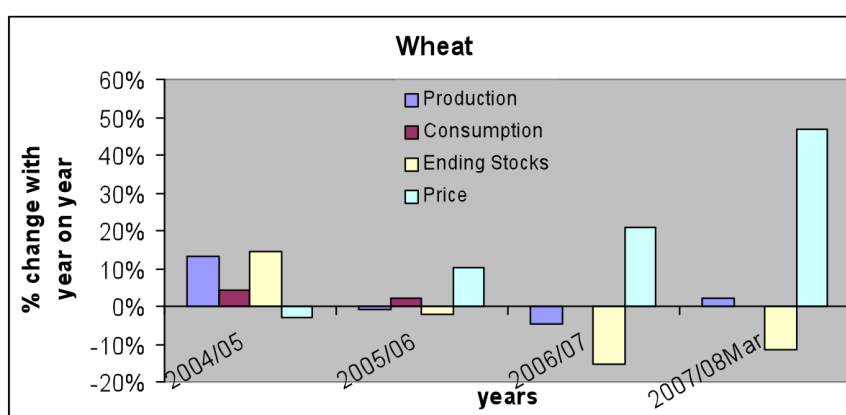
**Figure 3. Historical data**

Figures 4(a), 4(b), and 4(c) show trends since the year 2004. While consumption of coarse grains and rice has increased, the consumption of wheat has remained constant. Increase in coarse grain consumption was driven by increase in demand in the United States and to a lesser extent from EU and China. The increase in U.S. demand is attributable to the increase in production of ethanol from maize.

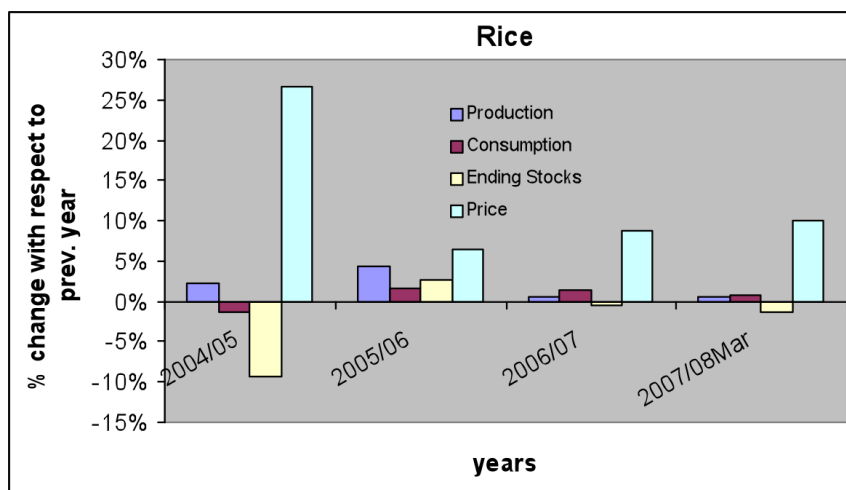
[Recent trends for coarse grains]



[Recent trends for wheat]



[Recent trends for rice]

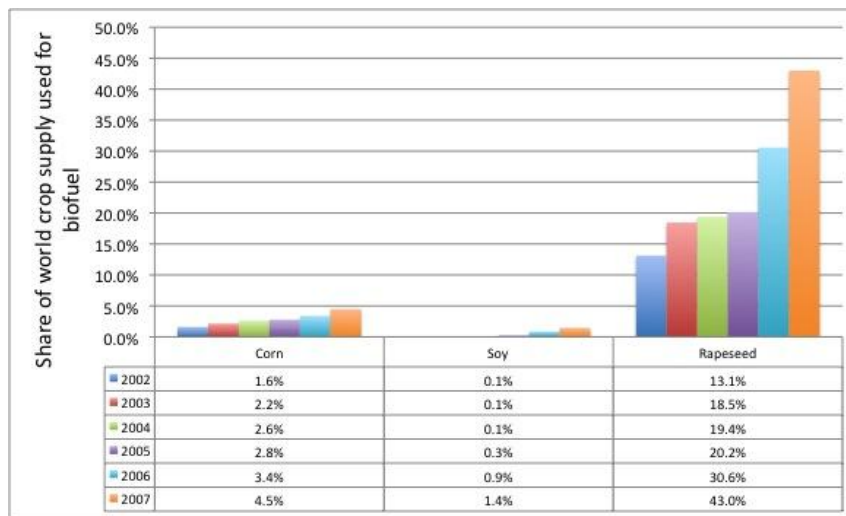


**Figure 4. Trends in grain**

Figure 5 shows for corn, soybean, and rapeseed the share of the total supply of each crop allocated for biofuel in recent years. We can see that the share of crops allocated to biofuels is substantial for rapeseed but not for corn and soybean. This results in biofuel becoming an important factor for increase in price of rapeseed, but less important for other crops, as will be



demonstrated below.



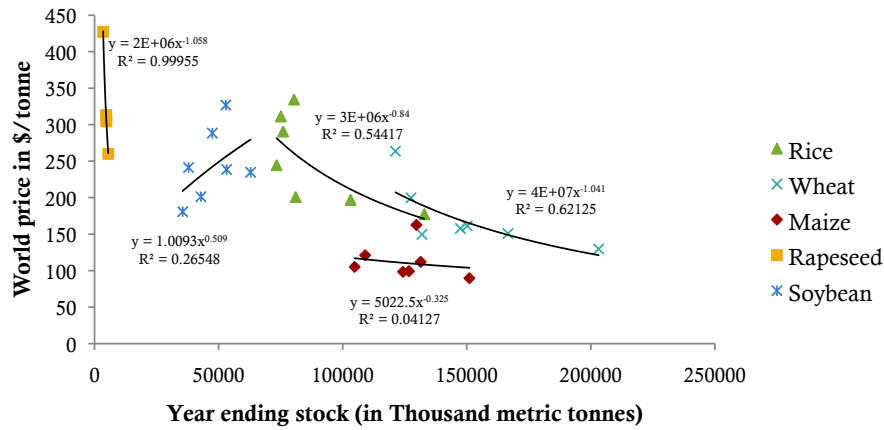
**Figure 5. Crop use for biofuel as a share of world crop supply**

Rice consumption, which is concentrated in Asian countries, increased 40% in the last 30 years, from 61.5 kilogram (kg) per capita to about 85.9 kg per capita. In addition, most rice is consumed in the same country where it is produced. This is one of the most important characteristics of the rice markets. Domestic rice markets are segmented and often one of the most protected.

Overall demand for food and feed due to economic growth and population growth (in developing countries) and demand for biofuels (in OECD countries) accompanied by slow rates of increase in output and adverse weather shocks have meant demand exceeded production in recent years leading to a drawing down of inventory levels which have reached a historical low.

#### **4. The story: Some descriptive statistics**

Worldwide growth in demand during the last several decades, coupled with a slowdown in agricultural production growth, reduced global stockpiles of basic commodities like corn, soybeans, and wheat [66] (see also Figure 6). Lower stocks, in turn, made it more likely that new sources of demand (e.g., biofuels), or disruptions to supply (e.g., drought), will result in large price changes.



**Figure 6. The observed correlation between price and inventory**

The spike in food commodity prices was not instantaneous, but resulted from a steady but gradual decline in stock-to-use. On the supply side, sluggish growth in world food production between 1995 and 2003, and a decline of stock-to-use ratio of world grain and oilseed stocks from 35% in 1985 to less than 15% in 2005 [66] – Stock-to-use ratio declined by more than 50%. Low food commodity prices over the last several decades reduced incentives for maintaining food stockpiles and for funding research and development to increase yields. Regulation in key regions also hampered research and development of yield-enhancing technologies.

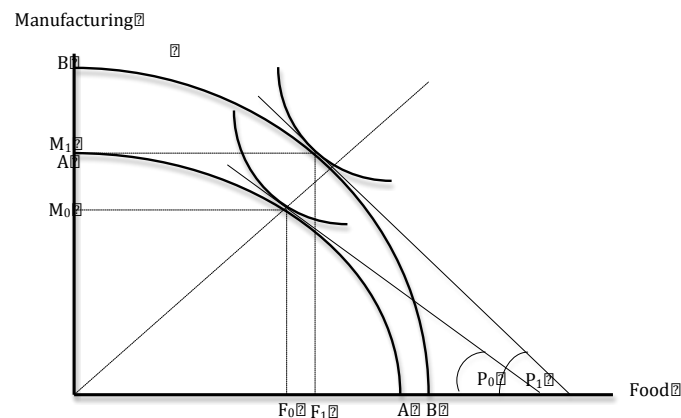
The sluggish growth in food production, coupled with rapid growth in manufacturing production, causes biased expansion of the production possibility frontier toward manufacturing goods.<sup>10</sup> Agricultural output in the emerging markets for the last two decades has been at most about half that of GDP growth. In China, 20% of humanity and the world's largest consumer and producer of food, non-agriculture productivity has been growing 3-5 times faster than agriculture.

This bias suggests higher food prices. We illustrate this graphically in figure 7. Assume the world is producing food, denoted  $F$ , and manufacturing, denoted  $M$ , with increasing opportunity costs, and homothetic preferences. In addition, normalize the price of manufacturing to 1. Then, curve  $AA$  in Figure 7 depicts the world production possibility frontier before biased growth. The equilibrium price equals  $P_0$ , and the amount of food and manufacturing produced and consumed are  $F_0$  and  $M_0$ , respectively. Introducing growth that

<sup>10</sup>Although Mitra and Martin [45] found that agriculture and manufacturing growth rates are converging, but the productivity of several commodities like wheat and soybeans have been lagging because of regulation that did not enable adopting of new biotechnologies (Alston et al. [4], Sexton et al. [62] and Graff et al. [27]).

is biased toward manufacturing results in the production possibility frontier  $BB$ , such that equilibrium consumption and production are now  $F_1$  and  $M_1$ . Although both food and manufacturing production and consumption increase, the equilibrium price of food after expansion is higher. The sluggish growth in production of food results in higher food prices. Although decomposing the supply side is outside the scope of this work, this simple example illustrates how underinvestment in agricultural productivity contributes to higher food prices, while employing a general equilibrium framework.<sup>11</sup>

In the 1980s and 1990s growth in agriculture outpaced growth in other sectors (Martin and Warr, [45]) and therefore the terms-of-trade moved against agriculture. However, in the late 1990s and the beginning of the 21st most of the developing world (e.g., China, India, Indonesia, and now Africa) experienced very high growth rates (above 4% and in some major countries around 10%), as documented in Nin-Pratt et al. [50] and Fuglie and Schimmelpfennig [22], resulting in the terms-of-trade changing in favor of agriculture. Furthermore, from a partial equilibrium perspective, the economic growth also results in strong demand growth for food, which also suggests that the price of food increases.



**Figure 7. The production possibility frontier and biased growth**

At the same time, strong global growth in average income and rising population (roughly 75 million people worldwide per year), particularly in developing countries, increased food and feed demand. As per capita incomes rose, consumers in developing countries not only increased per capita consumption of staple foods, but also diversified their diets to include more meats, dairy products, and vegetable oils. This, in turn, amplified rising demand for grains and oilseeds used as feed. To illustrate this, we computed the correlation coefficient between consumption and Gross Domestic Product per capita (GDP/capita). Although we do

<sup>11</sup>Hochman et al. [37] showed, while employing a general equilibrium trade model, that technological innovation in the manufacturing sector suggests more demand for energy, and thus more demand for biofuels.

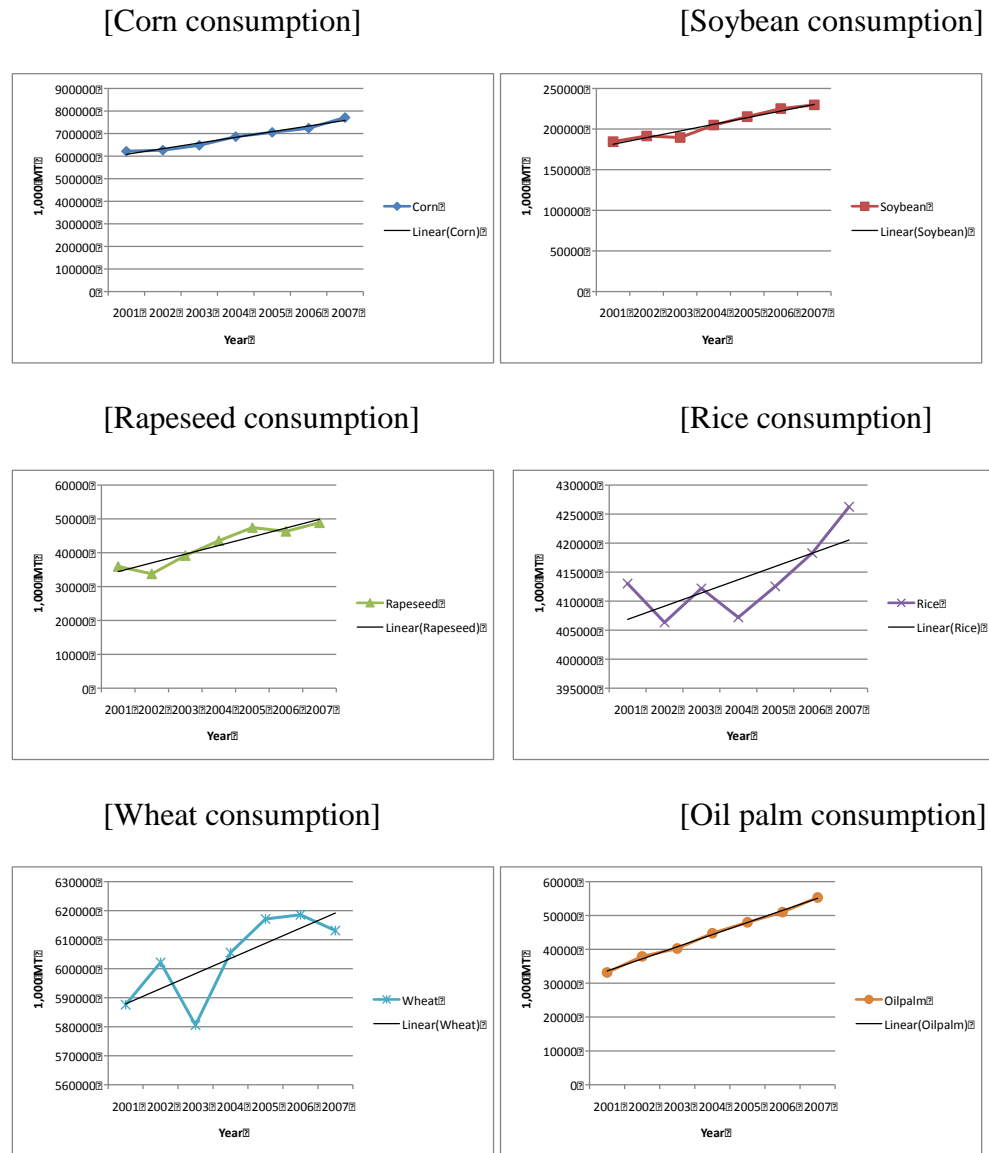
not hold all other factors constant, and the correlation between consumption and GDP/capita does not identify causation, it does suggest a strong positive linear relation between consumption and income at the world level for corn, soybean, rapeseed, and oil palm, and correlation coefficient of about 0.75 for rice and wheat (Table 2). The positive correlation computed above suggests that income is an important factor affecting consumption, and thus prices. Note that although globally the correlation between consumption and income is positive, in some regions it may be negative. Most notably, corn, rice, and wheat consumption in China declined during 2001 to 2007. Below we use income elasticity of demand from existing literature to incorporate income growth into our analysis.

**Table 2. Correlation between income and consumption of major agricultural commodities in major regions during 2001 to 2007**

| <b>Region</b>    | <b>Corn</b> | <b>Soybean</b> | <b>Rapeseed</b> | <b>Rice</b> | <b>Wheat</b> | <b>Oilpalm</b> |
|------------------|-------------|----------------|-----------------|-------------|--------------|----------------|
| <b>Argentina</b> | 0.87        | 0.99           |                 | 0.39        | -0.04        |                |
| <b>Brazil</b>    | 0.89        | 0.89           |                 | -0.13       | 0.80         | 0.97           |
| <b>China</b>     | -0.53       | 0.97           | 0.10            | -0.94       | -0.44        | 0.93           |
| <b>EU27</b>      | 0.68        | -0.63          | 0.96            | 0.80        | 0.16         | 0.97           |
| <b>India</b>     | 0.78        | 0.90           | 0.59            | 0.51        | 0.66         | 0.28           |
| <b>US</b>        | 0.82        | 0.53           | 0.81            | 0.71        | -0.50        | 0.89           |
| <b>ROW</b>       | 0.98        | 0.35           | 0.98            | 0.98        | 0.86         | 0.99           |
| <b>World</b>     | <b>.98</b>  | <b>.98</b>     | <b>.94</b>      | <b>.74</b>  | <b>.76</b>   | <b>.99</b>     |

Figures 4a-4f depict world consumption of various coarse grains and oil crops.

1. It illustrates the upward trend in global consumption from 2001 to 2007 for the various crops. From 2001 to 2007, demand grew, and the demand curve for the different crops shifted up and to the right. For some crops, however, the growth rate was larger than for others. Whereas corn demand grew by about 30%, rapeseed demand grew by almost 100% from 2001 to 2007.
2. In addition, growth was not symmetric across regions. Whereas globally consumption of all crops increased with income (at the world level, income is positively correlated with consumption, and world income grew throughout the period investigated), in some regions consumption of certain crops decreased. For example, corn, rice, and wheat consumption in China went down by 12.7%, 23.7%, and 20.9%, respectively, although global consumption increased by 24.0%, 3.2%, and 4.3%, respectively.

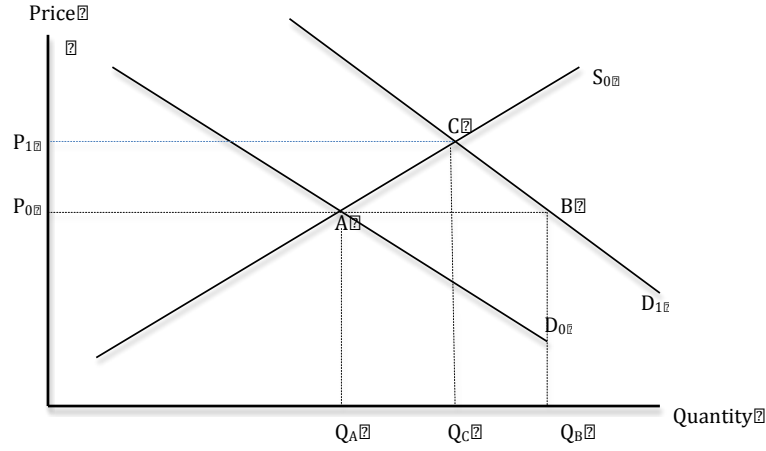


**Figure 8. World consumption of major crops over time**

Under a competitive equilibrium, supply equals demand (point A in Figure 9). There is no pressure for prices to change. As Ivanic and Martin [38] show, while employing the GTAP model and assuming uniform productivity growth across agriculture and non-agriculture products, although the real agricultural prices would rise over the period to 2050 growth in income will result in both changes in demand and supply. The change in demand is depicted in Fig. 9, whereas both changes are depicted in Fig. 10.

A shift in the demand curve, for instance, due to higher income or biofuels, all else being constant, results in excess demand. If only demand shifted, then at price  $P_0$  in Figure 9 the quantity of goods demanded by consumers is  $Q_B$ . Conversely, the quantity of goods that producers are willing to produce is  $Q_A$ . There are not enough crops produced to satisfy the quantity demanded by consumers. This excess demand results in upward pressure on prices,

making suppliers want to supply more crop and bringing the price to its new equilibrium level, i.e.,  $P_1$  and  $Q_C$  in Figure 9.



**Figure 9. Excess demand creates pressure for price increase**

Now assume supply, in addition to demand, shifted to the right. These shifts result in excess demand when the demand curve shifted relatively more. Figure 10 depicts this scenario. At equilibrium, we observe price and quantity,  $P_2$  and  $Q_E$ , respectively. The excess demand leading to this new equilibrium should be computed at the original price level of  $P_0$ , and in our example equals  $Q_B - Q_F > 0$ . The excess demand created upward pressure on prices, and resulted in an equilibrium price of  $P_2 > P_0$ . To compute the excess demand, we need to adjust for the price change. This is done by moving along the new supply and demand functions, while using own-price elasticity of demand and supply and the observed price and quantity changes. Put differently, excess demand caused the quantity demanded to decrease by  $Q_B - Q_E$ , and the quantity supplied to increase by  $Q_E - Q_F$ . The own-price demand and supply elasticities are  $\eta_D$  and  $\eta_S$ , respectively:

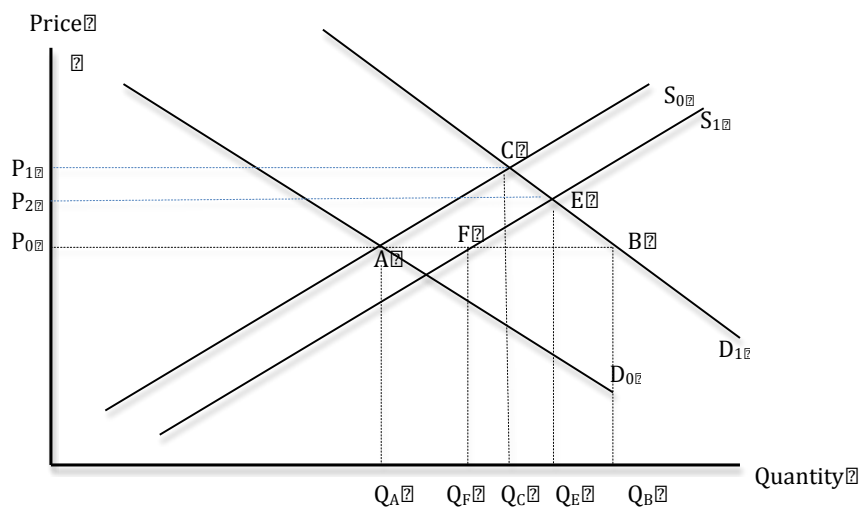
$$Q_B - Q_E = \eta_D \cdot \frac{P_0 - P_2}{P_2} \cdot Q_E$$

$$Q_F - Q_E = \eta_S \cdot \frac{P_0 - P_2}{P_2} \cdot Q_E$$

The excess demand surplus equals the sum of the two, i.e.,  $Q_B - Q_F$ .

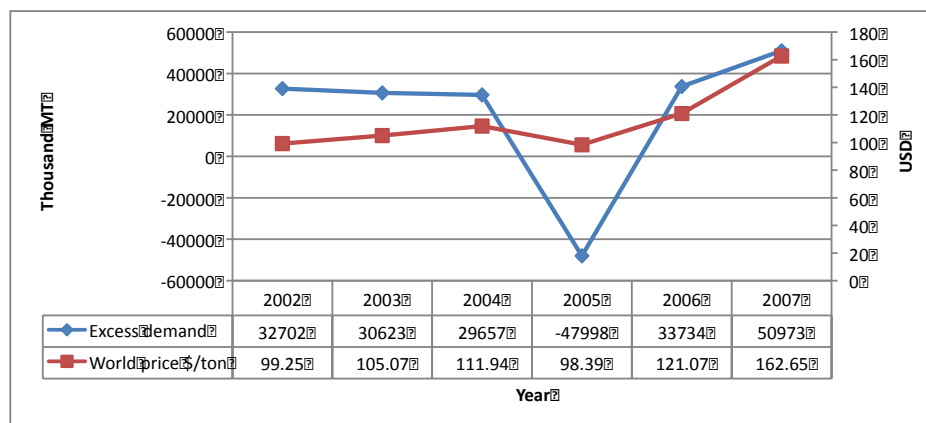
When introducing inventory, global domestic consumption does not need to equal production in equilibrium, but it should equal production minus the change in the level of global

inventories (note that we assume balanced trade, such that globally total imports equal total exports). This scenario is what we observe for the different crops (Figure 10). World production was more sluggish, on average, and domestic consumption outpaced production for most periods/crops. This depleted inventories (see Figure 19 below), which led us to the 2007-08 price spike. Rice is an exception. To this end, and following the literature, trade restrictions played a key role in the spike in rice prices [1], where exporting countries limited exports and mitigated upward pressure on domestic prices only to exacerbate the spike in the price of rice in the rice-importing countries (which includes many least-developing countries).

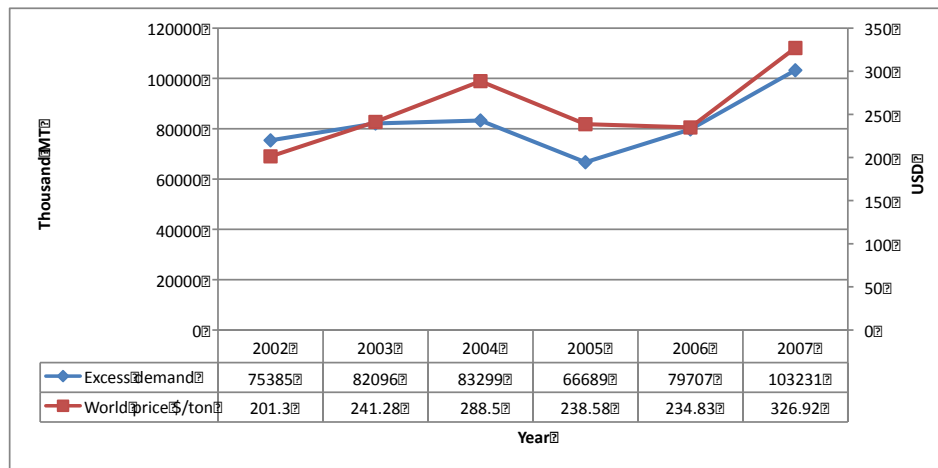


**Figure 10. Price increases when supply shifts out less than does demand**

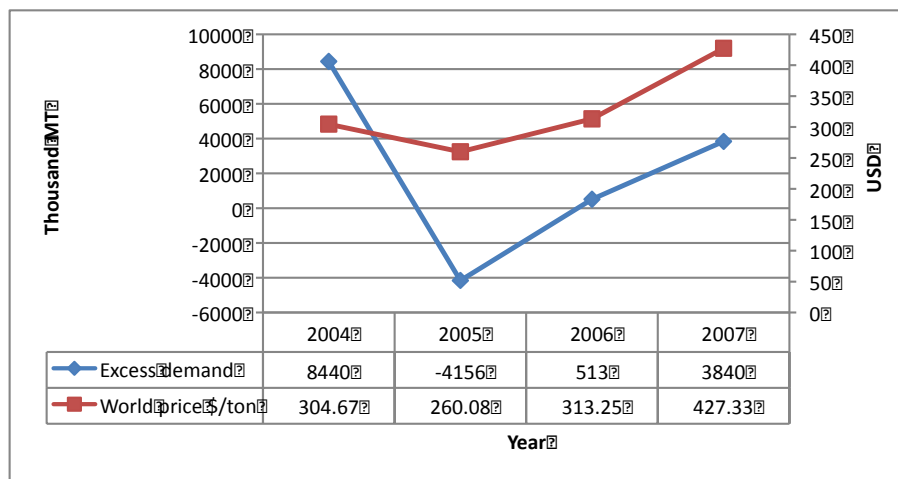
### [Production and domestic consumption of corn]



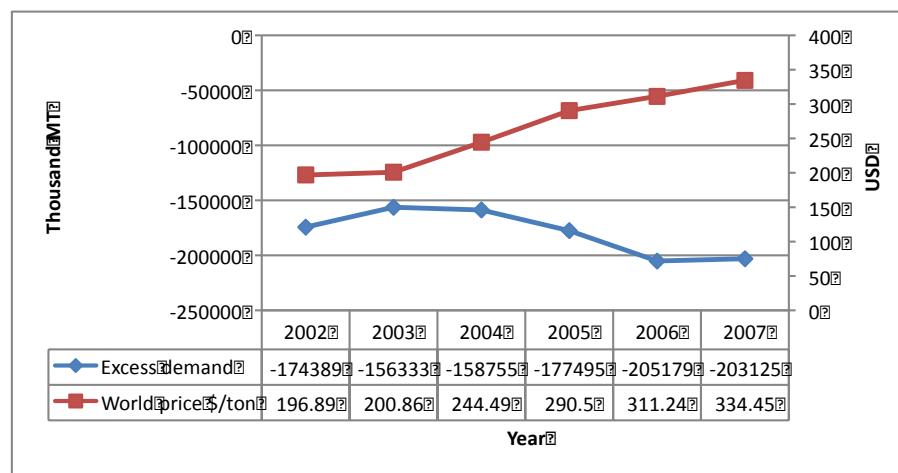
[Production and domestic consumption of soybeans]



[Production and domestic consumption of rapeseeds]

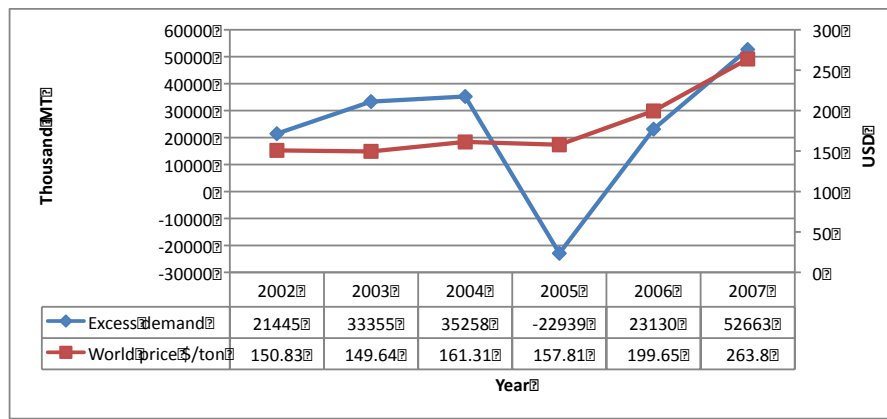


[Production and domestic consumption of rice]

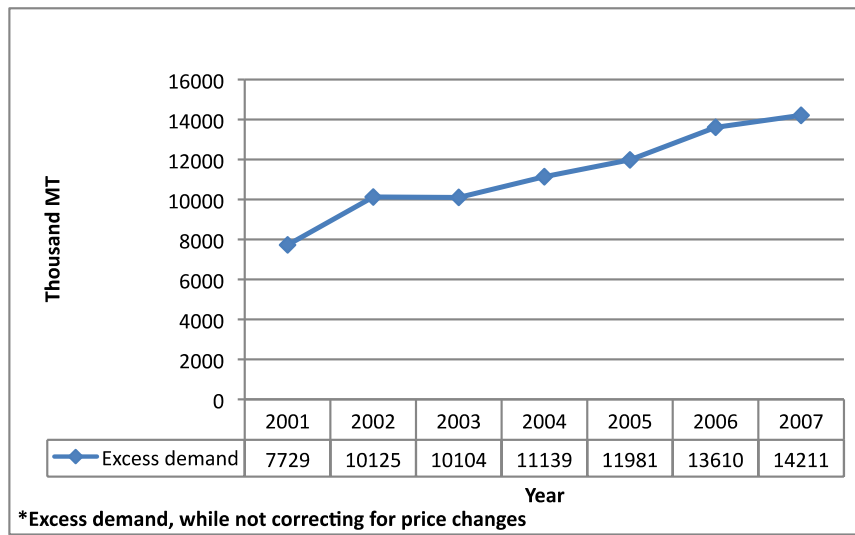




[Production and domestic consumption of wheat]



[Production and domestic consumption of oilpalm]

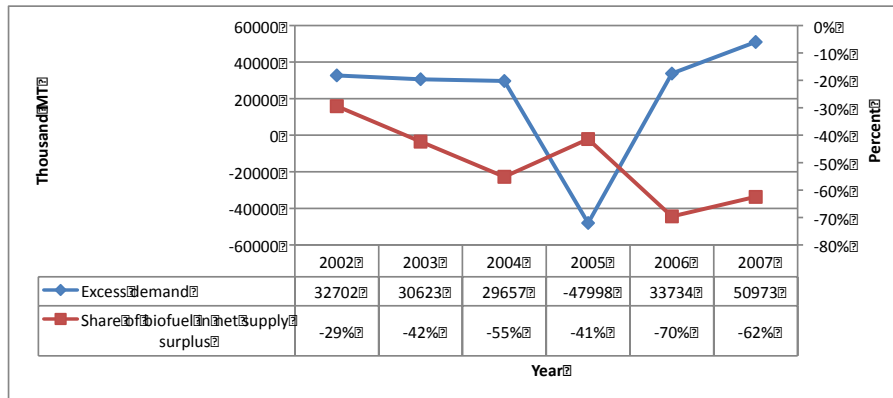


**Figure 11. Production and domestic consumption**

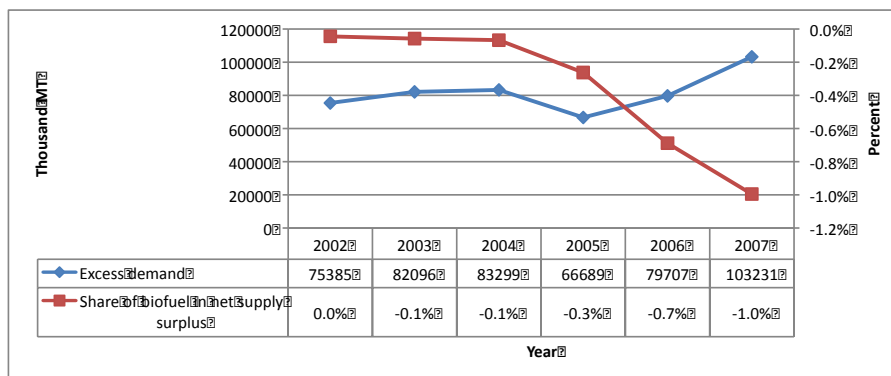
The use of biofuels had been modest for several decades, but production rose rapidly in the United States beginning in 2003 and in the EU starting in 2005. Output increased in response to mounting concerns about rising petroleum prices, the availability of oil supplies, and the environmental impacts of fossil fuels. The growth in worldwide biofuels demand contributed to higher prices for biofuel feedstocks. Biofuel feedstocks like corn, sugarcane, soybeans, and rapeseed now have new uses beyond food and feed. The demand curve now expands and biofuel, like income and population growth, caused demand to shift up and to the right. The share of biofuel in excess demand, however, varies with crops. Assume demand and supply of own-price elasticity of -0.1 and 0.1, respectively. We use these elasticities to compute the excess demand. Whereas the share of biofuel in excess demand increased for corn from 29% in 2001 to more than 60% by 2007, it was less than 1% for soybean. Rapeseed is at the other

extreme, where the share of biofuel dwarfs the excess demand (Figure 11). Note that introducing higher elasticities (0.2 and -0.2, respectively), results in a smaller biofuel impact because the excess demand will now be larger.

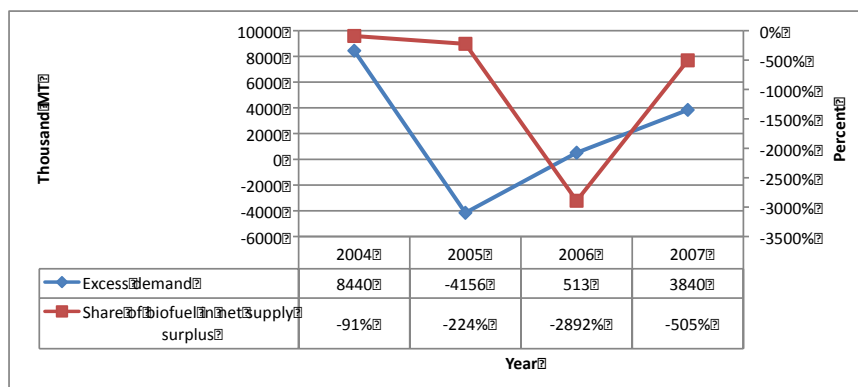
[Excess demand and supply of corn for ethanol]



[Excess demand and supply of soybean for biodiesel]



[Excess demand and supply of rapeseed for biodiesel]



Figure

## 12. Share of crop demand for biofuel in excess crop demand

The increase in food commodity prices over the last several years is part of a general increase in global commodity prices, including minerals, metals, and energy. Although the food commodity price index rose to a historic high in 2007-08, the price indices for all commodities, and for crude oil in particular, have significantly outpaced it. In fact, between January 2002 and July 2008, the IMF price index for food commodities rose 130%, compared with 330% for all commodities and 590% for crude oil.

Another factor to consider is the increase in energy prices [33]. To this end, the energy impact on food commodity prices should be divided into two factors: the allocation of land to biofuel crops (which reduces food and feed availability and increases the aggregate demand for food commodities), and the increase in energy prices (which increases production costs and reduces the supply of food commodities). See also Hochman et al. [32]. First-generation biofuels, which are derived primarily from corn and sugarcane, compete with food and feed, resulting in higher demand for agricultural commodities and thus in higher prices. The introduction of biofuels, however, also lowers fuel prices [54]. Yet, the literature fails to recognize that lower fuel prices affect farm-level costs. Introducing energy markets, with all its complexity, to our multi-market framework reduces the impact of biofuels on food commodity prices further.

To reiterate, the data show that successive years of positive excess demand led to the gradual depletion of inventory, which reached an historical low in 2008.

The following section discusses the implications of inventory and describes one approach for modeling the demand for inventory in a multi-market equilibrium framework.

## **5. An analytical framework with inventory demand**

The peak of the food crisis marked the depletion of stored grain stocks to historically low levels that had not been witnessed since the 1970s [52, 68]. For storable goods, the ability to adjust the level of inventory can play a crucial role in maintaining price stability and reducing price volatility when there is a supply or demand shock [68]. During periods of excess supply, demand from storers protects producers from rapidly descending prices, while during periods of scarcity; supply from inventory protects consumers from rapidly ascending prices.

We do not focus on the theoretical underpinnings of speculative inventory, which is dynamic and forward looking. Anticipation of future inventory decisions affects current ones, and this complexity is augmented by the inventory constraints, i.e., one cannot borrow from the future or that inventory cannot be negative [68]. Instead we assume that one can estimate an

empirically derived inventory demand function using historical data on prices and inventory.

Formally harvest,  $H$ , is a function of past period crop prices  $p_j^{t-1}$ , where  $p_j^t = (p_{1,j}^t, \dots, p_{C,j}^t)$  and  $c \in \{1, \dots, C\}$  such that  $C$  denotes the set of crops and  $j$  denotes a region. Assuming prices follow a random walk, then suggests that the end of period  $t$  inventory is only a function of current and past prices, as well as the beginning stocks in period  $t$ , i.e.,  $I^t = f(p_j^t, p_j^{t-1}, I^{t-1})$ .

Consumption demand for crops comprises of demand for food ( $D_{cf}$ ) and demand for biofuel production ( $D_{cb}$ ). Both demand for food/feed and demand for biofuels are a function of the price of crops ( $p_j^t$ ) and the price of energy ( $p_{e,j}^t$ ). In addition, demand for food and feed at region  $j$  at time  $t$  is a function of GDP per capita,  $GDPpc_j^t$ .

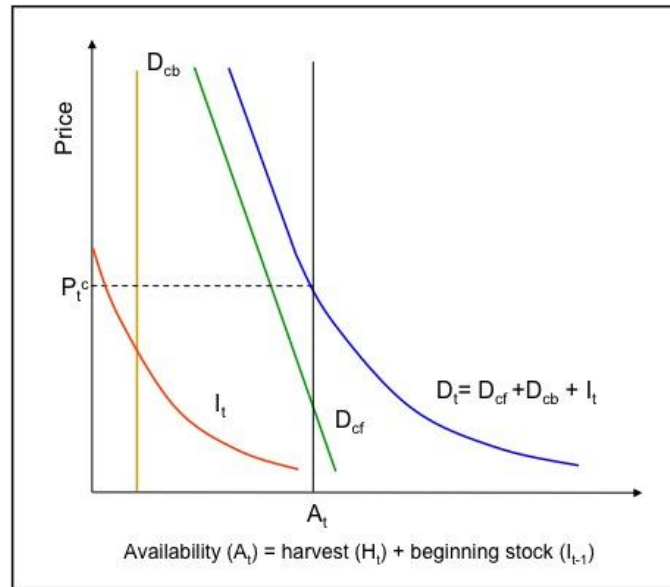
With inventory, the equilibrium price does not need to equate harvest,  $H_{c,j}^t$ , plus imports,  $IM_{c,j}^t$ , with consumption,  $D_{cf} + D_{cb}$ , plus exports,  $EX_{c,j}^t$ . However, it should equate world supply,  $\sum_j (H_{c,j}^t + IM_{c,j}^t)$ , plus global beginning stock,  $I^{t-1}$ , with world demand,  $\sum_j (D_{c,j}^t + EX_{c,j}^t)$ , plus global ending stocks,  $I^t$ :

$$\sum_j (H_{c,j}^t + IM_{c,j}^t) + I_c^{t-1} = \sum_j (D_{c,j}^t + EX_{c,j}^t) + I_c^t. \quad (1)$$

The left-hand side can be called total availability,  $A_t$ , at time  $t$ . The equilibrium condition can now be written as

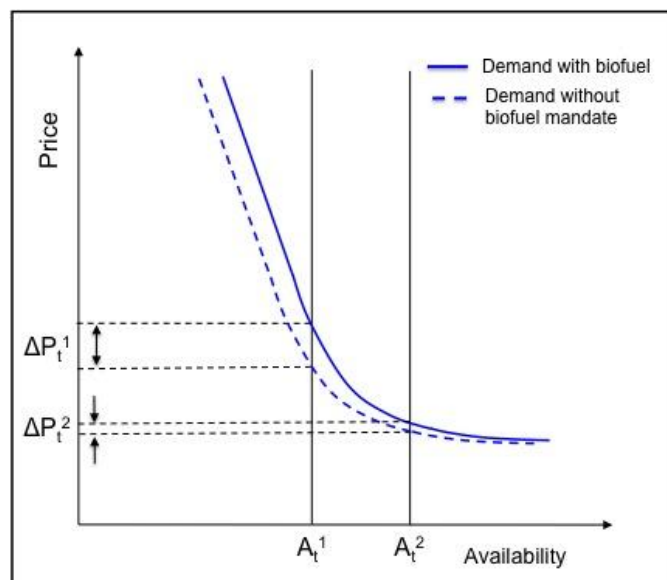
$$\begin{aligned} & \sum_j (H_{c,j}^t + IM_{c,j}^t(p_j^t, p_e^t, GDPpc_t)) + I_c^{t-1} \\ &= \sum_j (D_{cf,j}^t(p_j^t, p_e^t, GDPpc_j^t) + D_{cb,j}^t(p_j^t, p_e^t) + EX_{c,j}^t(p_j^t, p_e^t, \{GDPpc_k^t\}_{k \neq j})) \\ & \quad + I_c^t(p^t, p^{t-1}, I_c^{t-1}), \end{aligned} \quad (2)$$

Knowing  $H_t$ ,  $I_{t-1}$ ,  $p_e^t$ , and  $p^t \equiv \{p_j^t\}_j$ , and the shape of demand functions  $D_{cf}$ , one can determine the effect of different levels of biofuel mandates  $D_{cb}$  on crop prices.



**Figure 13. Graphical representation of equilibrium with demand for inventory**

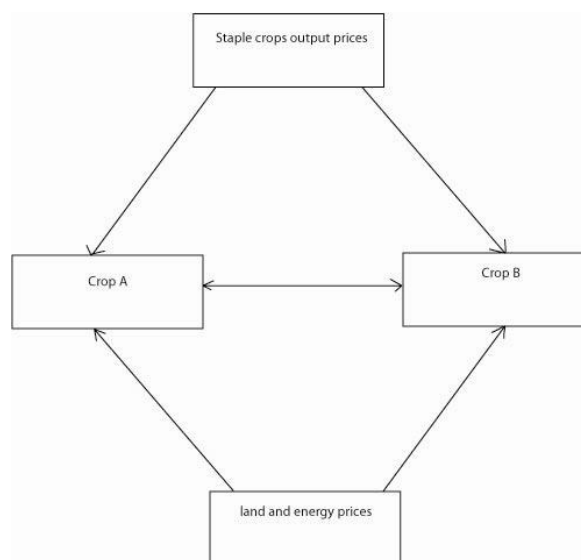
A graphical representation of such equilibrium is shown in Figure 13. This model also suggests that given demand exceeds harvest, lower beginning stocks lead to higher prices. Therefore, a fixed biofuel mandate will cause prices to increase more as the level of inventories declines. Figure 14 shows total demand for a crop under two situations, with and without biofuel, and total availability under two situations, with a high and low level of inventory. We can see that as availability decreases, the impact of a biofuel mandate increases. This also suggests that holding harvest constant, a model without inventory overestimates the price effect of biofuel.



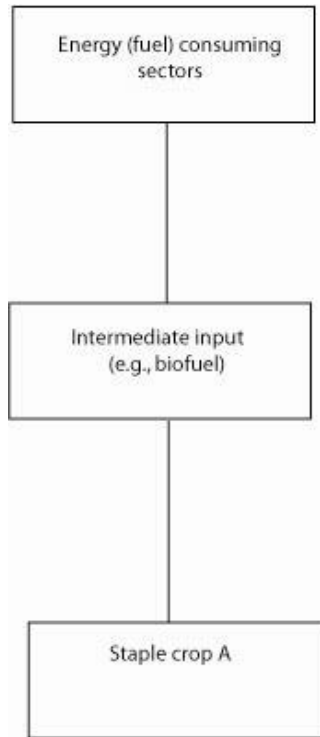
**Figure 14. Biofuel effect depends on crop availability: Low availability causes higher price impact**

## 6. Multi-market analysis

The simple partial equilibrium model, while important, has some limitations. The actors in the market are characterized as either producers or consumers, and their welfare is aggregated accordingly. For instance, when analyzing the staple crop market, we implicitly assume that the benefits to biofuel refineries are part of the consumer surplus. Being able to disaggregate markets is, therefore, crucial if we are to accurately describe, prescribe, and explain policy's impact on food commodity prices. Although different from the general equilibrium model (the multi-market model does not assume consumption expenditures are endogenous and depends on factor payments and endowment incomes, and it does fix factor prices), the multi-market framework does allow a partial disaggregation of the vertical structure to (i) crops for food production and processing and (ii) crops for energy production, as well as a horizontal structure disaggregation in which the feedback effects between the different crop markets are also required. Whereas the horizontal structure (Figure 15) captures the effect of input prices on allocation of resources among the different staple crops, the vertical structure (Figure 16) captures the interactions along the supply chain of a staple crop.



**Figure 15. Horizontal structure**



**Figure 16. Vertical structure**

Although these effects have been modeled extensively in GTAP, FAPRI, and IFPRI models, to the best of our knowledge, the importance of inventory and its effect on outcomes has not yet been analyzed.

### *6.1. Horizontal structure*

Different staple crops compete for the same input; namely, land and energy. Thus, an increase in China's demand for soybeans may trigger a decline in land allocated to competing crops such as maize, which in turn causes supply of maize to contract. Strong growth rates in China not only cause the price of soybean to increase, but it also increases the price of other staple crops that compete with soybeans over land. To this end, the cross-elasticity of quantity of maize supplied with respect to the price of soybean is negative.

Similar effects exist when staple crops are used to produce energy, as opposed to food. Increase in demand for maize-ethanol increases the amount of land allocated to maize-ethanol, and it reduces land allocated to other crops such as soybeans, as well as maize for food and feed. An increase in the price of energy results in higher demand for maize, and thus higher prices; albeit quantity of maize demanded for food and feed is now lower.

Consumers may substitute between different staple crops. An increase in the price of crop A is

accompanied by an increase in demand of crop B. As the price of maize increases, maize for feed may be substituted with soybeans. Similarly, as the price of rice increases, wheat consumption increases. On the other hand, the nutritional characteristics of soybean for feed may complement those of maize—the two crops may then be complements, not substitutes.

Identifying the dominant forces between the different staple crops is crucial for correctly disaggregating the horizontal structure. In sum, the horizontal structure is influenced by (i) factors affecting derived demand for inputs (especially land and energy), and by (ii) factors influencing demand for the different crops, especially growth in disposable income and biofuels (ethanol and biodiesel) consumption. Many of these factors are not specific to the horizontal structure of crop production, and are also affected by the vertical structure. Therefore, and to better understand these cross-market effects, we next disaggregate the vertical structure.

## *6.2. Vertical structure*

Demand for staple crops is affected by the introduction of new markets, namely, ethanol and biodiesels. More specifically, production of ethanol and biodiesels created new demand for staple crops, which further increased the price of the feedstock (the staple crops used to produce biofuels). Increasing demand for staple crops triggers an increase in land allocated to crops used to produce first-generation biofuels, i.e., less land allocated to food and feed and more allocated to energy production. This effect is augmented when the price of crude oil—a main source of transportation fuel—increases [36]. The surge in crude oil prices during 2007 created a very profitable (although temporary) environment for crops used to produce biofuels [35]. Many farmers switched to crops used to produce ethanol and biodiesel, and limited the amount of crops sold to the food markets. The competition between uses (food, feed, and feedstock) within a feedstock market can become intense, much more than between food grain and feed grain. The vertical structure is influenced by input markets (especially energy), and by demand for the different end products, especially food and feed versus biofuel (ethanol and biodiesel) consumption.

## *6.3. The numerical model*

We now use the horizontal and vertical structure discussed above to model our empirical



model. Our model extends the single-region, single-crop model with inventory discussed above in section 3, to a multi-region framework, where demand for each crop is composed of food/feed, inventory, and where applicable, demand for biofuels. We apply the model for five major crops, namely, corn, soybean, rapeseed, rice, and wheat. With the exception of rice and wheat, all the other crops are currently being used to produce biofuel.

Biofuel from corn, soybean, and rapeseed is jointly produced along with a co-product that is itself a substitute for the raw grain or the oilseed. For instance, in the case of corn, 1 bushel (56 pounds) of corn yields approximately 2.75 gallons of ethanol and 18 pounds of distiller grains, which is a substitute for corn grain. A fraction of the quantity of original crop used for biofuel is replaced in the form of co-product. Therefore, for these three crops, we compute an effective demand of the particular crop for biofuel, which equals the crop consumption for biofuel minus the quantity of a co-product. In the case of corn, the effective demand of corn is  $0.68 (= 1 - 18/56)$  bushels per 2.75 gallons of ethanol. We assume that biofuel production function is of Leontief (fixed-proportion) type.

We divide the world into seven major regions, namely, Argentina, Brazil, China, European Union (EU-27 countries), India, United States, and an aggregate that represents the rest of the world (ROW), and focus on the time period between the year 2001 and the year 2007.

Let  $S_{i,j}^t$  be harvest of crop  $i$  in region  $j$  at time  $t$ ,  $D_{fi,j}^t$  is demand of crop  $i$  in region  $j$  at time  $t$  for food/feed consumption,  $D_{bi,j}^t$  is demand for crop  $i$  in region  $j$  at time  $t$  for biofuel production, and  $I_{i,w}^t$  is global demand for inventory of crop  $i$  at time  $t$ . Let  $a, b, c, d, e, f, g, h, k$ , and  $l$  denote constants which are determined through calibration of the supply and demand functions,  $\phi_j^t$  denotes exchange rate of currency in region  $j$  at time  $t$  with respect to the US\$,  $P_{i,w}^t = p_{i,j}^t / \phi_j^t$  is world price of crop  $i$  at time  $t$ , and  $P_{e,w}^t = p_{e,j}^t / \phi_j^t$  is world price of energy at time  $t$ .

With the exception of the demand for inventory, we assume a linear structure for supply and demand. The linear structure generally serves as a good approximation for small disturbances or shocks. Supply, which is the sum of harvest and imports of crop  $i$  in region  $j$  at time  $t$ , is modeled as,

$$S_{i,j}^t = a_{i,j} + b_{i,j} \phi_j^t P_{i,w}^t + c_{i,j} \phi_j^t P_{e,w}^t. \quad (3)$$

Demand, which is the sum of domestic demand for food/feed consumption and the demand for

exports of crop  $i$  in region  $j$  at time  $t$  is modeled as,

$$D_{fi,j}^t = d_{i,j} + e_{i,j}\phi_j^t P_{i,w}^t + k_{i,j}\phi_j^t P_{e,w}^t + l_{i,j}GDPpc_j^t \quad (4)$$

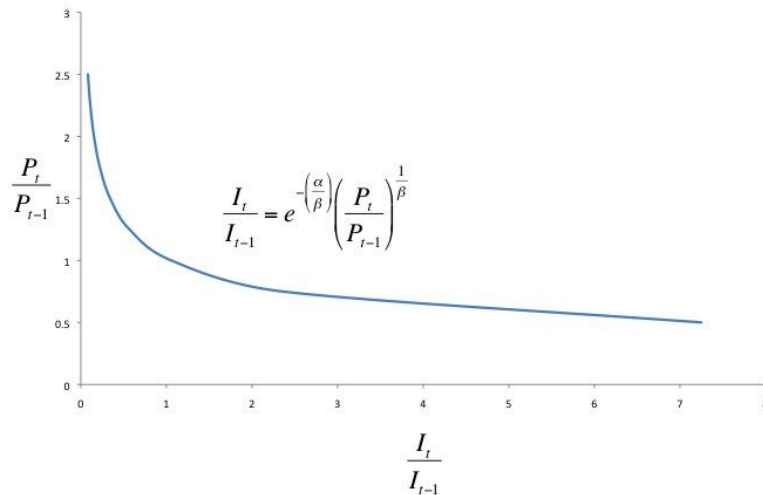
Similarly, the derived demand for crop  $i$  for biofuel production in region  $j$  at time  $t$  is modeled as

$$D_{bi,j}^t = f_{i,j} + g_{i,j}\phi_j^t P_{i,w}^t + h_{i,j}\phi_j^t P_{e,w}^t, \quad (5)$$

In the case where biofuel production is determined through a mandate, the derived crop demand for biofuel is simply a fixed proportion of the mandate.

Crop demand for inventory (Eq. 6) is represented as a nonlinear function of price and follows Carter et al. [14]. This equation is depicted graphically in figure 17 for corn inventory using the parameters for  $\alpha$  and  $\beta$  as estimated by Carter et al. This clearly shows that larger changes in inventory levels would correspond to smaller changes in crop prices,

$$I_{i,w}^t = e^{\frac{-\alpha_i}{\beta_i} \left[ \frac{P_{i,w}^t}{P_{i,w}^{t-1}} \right]^{\frac{1}{\beta_i}}} I_{i,w}^{t-1} \quad (6)$$



**Figure 17. Inventory demand function**

#### 6.4. Model calibration

We calibrate the crop supply and crop demand functions for each crop, region, and year, once

with demand for inventory and once without. The calibrated demand and supply parameters are used to numerically calculate the effect of each of the different shocks on the observed price in a given year.

**Table 3. Range of elasticities contained in the literature cited in FAPRI database**

| Commodity | Region    | Supply (1) |      | Demand (2) |       | Income (3) |      |
|-----------|-----------|------------|------|------------|-------|------------|------|
|           |           | min        | max  | min        | max   | min        | max  |
| Corn      | Argentina | 0.65       | 0.75 | -0.4       | -0.3  | 0.35       | 0.45 |
|           | Brazil    | 0.37       | 0.47 | -0.4       | -0.1  | 0.35       | 0.45 |
|           | China     | 0.08       | 0.18 | -0.14      | -0.6  | 0.75       | 1    |
|           | EU        | 0.01       | 0.13 | -0.44      | -0.24 | 0.1        | 0.2  |
|           | India     | 0.16       | 0.26 | -0.28      | -0.22 | 0.75       | 1    |
|           | U.S.      | 0.45       | 0.55 | -0.24      | -0.1  | 0.05       | 0.1  |
|           | ROW       | 0.45       | 0.55 | -0.43      | -0.21 | 0.4        | 0.6  |
|           |           |            |      |            |       |            |      |
| Soybeans  | Argentina | 0.27       | 0.37 | -0.3       | -0.2  | 0.35       | 0.45 |
|           | Brazil    | 0.29       | 0.39 | -0.21      | -0.11 | 0.35       | 0.45 |
|           | China     | 0.4        | 0.5  | -0.25      | -0.15 | 0.75       | 1    |
|           | EU        | 0.14       | 0.24 | -0.3       | -0.2  | 0.1        | 0.2  |
|           | India     | 0.31       | 0.41 | -0.35      | -0.25 | 0.75       | 1    |
|           | U.S.      | 0.18       | 0.28 | -0.48      | -0.31 | 0.05       | 0.1  |
|           | ROW       | 0.18       | 0.28 | -0.48      | -0.31 | 0.4        | 0.6  |
|           |           |            |      |            |       |            |      |
| Rapeseed  | Argentina | 0.53       | 0.63 | -0.35      | -0.03 | 0.35       | 0.45 |
|           | Brazil    | 0.53       | 0.63 | -0.35      | -0.03 | 0.35       | 0.45 |
|           | China     | 0.21       | 0.31 | -0.35      | -0.25 | 0.75       | 1    |
|           | EU        | 0.23       | 0.33 | -0.13      | -0.03 | 0.1        | 0.2  |
|           | India     | 0.29       | 0.39 | -0.3       | -0.2  | 0.75       | 1    |
|           | U.S.      | 0.53       | 0.63 | -0.35      | -0.03 | 0.05       | 0.1  |
|           | ROW       | 0.53       | 0.63 | -0.35      | -0.03 | 0.4        | 0.6  |
|           |           |            |      |            |       |            |      |
| Rice      | Argentina | 0.27       | 0.37 | -0.43      | -0.38 | 0.35       | 0.45 |
|           | Brazil    | 0.27       | 0.37 | -0.43      | -0.38 | 0.35       | 0.45 |
|           | China     | 0.27       | 0.37 | -0.71      | -0.54 | 0.75       | 1    |
|           | EU        | 0.27       | 0.37 | -0.43      | -0.38 | 0.1        | 0.2  |
|           | India     | 0.27       | 0.37 | -0.43      | -0.38 | 0.75       | 1    |
|           | U.S.      | 0.27       | 0.37 | -0.87      | -0.77 | 0.05       | 0.1  |
|           | ROW       | 0.27       | 0.37 | -0.43      | -0.38 | 0.4        | 0.6  |
|           |           |            |      |            |       |            |      |
| Wheat     | Argentina | 0.36       | 0.46 | -0.39      | -0.28 | 0.35       | 0.45 |
|           | Brazil    | 0.38       | 0.48 | -0.38      | -0.27 | 0.35       | 0.45 |
|           | China     | 0.04       | 0.14 | -0.18      | -0.07 | 0.75       | 1    |
|           | EU        | 0.07       | 0.17 | -0.33      | -0.26 | 0.1        | 0.2  |
|           | India     | 0.24       | 0.34 | -0.37      | -0.32 | 0.75       | 1    |
|           | U.S.      | 0.43       | 0.53 | -0.35      | -0.25 | 0.05       | 0.1  |
|           | ROW       | 0.43       | 0.53 | -0.35      | -0.25 | 0.4        | 0.6  |
|           |           |            |      |            |       |            |      |

1. Own price elasticity of supply
2. Own price elasticity of demand
3. Income elasticity of supply

Key parameters in the calibration of these functions are elasticities of supply and demand, i.e., the sensitivity of a relative change in quantities supplied or demanded to a given relative change in (energy) prices. Given the wide range of elasticities reported in the literature and the sensitivity of the simulation to elasticities, for each crop we chose to sample 100 times from within a range of elasticities. The range of elasticities is shown in Table 3. The elasticity of supply and demand with respect to energy price is assumed to lie within the range  $[0, 0.15]$  and  $[-0.05, -0.02]$ , respectively. This reflects the assumption that demand is less responsive than is supply to energy prices.

Note that our specification does not include cross-price elasticities on the supply or the demand side. The reason for this is to overcome computational constraints. We chose to investigate the robustness of the results through a sensitivity analysis with respect to own-price, income, and energy elasticities and by employing alternative specifications of the demand function. Our computational capacity did not allow us to introduce cross-price elasticities to this numerical exercise. This limitation will be addressed in future work.

**Table 4. Inventory demand parameters**

| Parameter | corn    | soybean | rice   | wheat   |
|-----------|---------|---------|--------|---------|
| $\alpha$  | 0.0186  | 0.0186  | 0.0186 | 0.0186  |
| $\beta$   | -0.8004 | -.5096  | -.5096 | -1.4676 |

Following Carter et al. [14] we estimated the inventory demand parameters using instrumental variable techniques, because inventory is correlated with the disturbance, whereas harvest is uncorrelated with these disturbances but correlated with inventory (harvest is both exogenous and relevant). We estimated the inventory demand function, while using harvest as an instrumental variable. We tested alternative specifications and also introduced crop-specific dummy variables (Table 4). In all cases, however, we could not reject the hypothesis that the specification chosen is correct.

Given the relevant elasticities for each region, we calibrate the parameters  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$ ,  $f$ ,  $g$ ,  $h$ ,  $k$ , and  $l$  as follows:

$$b_{i,j} = \epsilon_{i,j} \frac{S_{i,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{i,w}^{\bar{t}}} \quad (7)$$

$$c_{i,j} = \sigma_{i,j} \frac{S_{i,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{e,w}^{\bar{t}}} \quad (8)$$

$$a_{i,j} = S_{i,j}^{\bar{t}} - b_{i,j} \phi_j^{\bar{t}} P_{i,w}^{\bar{t}} - c_{i,j} \phi_j^{\bar{t}} P_{e,w}^{\bar{t}} \quad (9)$$

$$e_{i,j} = \eta_{i,j} \frac{D_{fi,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{i,w}^{\bar{t}}} \quad (10)$$

$$d_{i,j} = D_{fi,j}^{\bar{t}} - e_{i,j} \phi_j^{\bar{t}} P_{i,w}^{\bar{t}} \quad (11)$$

$$g_{i,j} = \mu_{i,j} \frac{D_{bi,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{i,w}^{\bar{t}}} \quad (12)$$

$$h_{i,j} = \theta_{i,j} \frac{D_{bi,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{e,w}^{\bar{t}}} \quad (13)$$

$$f_{i,j} = D_{bi,j}^{\bar{t}} - g_{i,j} \phi_j^{\bar{t}} P_{i,w}^{\bar{t}} - h_{i,j} \phi_j^{\bar{t}} P_{e,w}^{\bar{t}} \quad (14)$$

$$k_{i,j} = \gamma_{i,j} \frac{D_{fi,j}^{\bar{t}}}{\phi_j^{\bar{t}} P_{e,w}^{\bar{t}}} \quad (15)$$

$$l_{i,j} = \frac{D_{fi,j}^{\bar{t}}}{\phi_j^{\bar{t}} GDP p c_j^t} \quad (16)$$

where  $\bar{t}$  denotes the year chosen for calibration,  $\epsilon_{i,j}$  is own-price elasticity of supply of crop  $i$  in region  $j$ ,  $\sigma_{i,j}$  is elasticity of supply of crop  $i$  in region  $j$  with respect to energy price,  $\eta_{i,j}$  is own-price elasticity of demand of crop  $i$  in region  $j$  for food/feed consumption,  $\mu_{i,j}$  is own-price elasticity of demand for crop  $i$  in region  $j$  for biofuel production,  $\theta_{i,j}$  is elasticity of crop demand for biofuel production with respect to energy price for crop  $i$  in region  $j$ , and  $\gamma_{i,j}$  is the income elasticity of demand of crop  $i$  in region  $j$ .

### 6.5. Description of the shocks

To calculate the impact of each of the various factors contributing to the change in average yearly price for each commodity, we shock the system (in our case the equation that represents

the market-clearing condition for each commodity) and calculate the counter-factual world price that would have prevailed for the commodity. We simulate four different types of shocks, namely, a biofuel shock (due to biofuel mandates), a food/feed demand shock (due to economic growth), an exchange rate shock, and an energy price shock. We simulate one shock at a time. For each type of shock, we set the value of the shocked parameter equal to its value in the base year. To give an example, the biofuel shock for corn in the year 2005 is computed as the ratio of the world corn biofuel production in 2001 (2.13 billion gallons) and world corn biofuel production in 2005 (4.8 billion gallons), which is equal to 0.44. We simulate each of these shocks for six years, 2002 through 2007. Furthermore, we simulate the shocks twice, once with a market for inventory and once without, where inventories are added to aggregate supply and demand. We perform 100 simulations of the scenario for the various shocks for each crop and for each time period. The reported value is the mean of these outcomes.

1. **Income shock:** To simulate the income shock, we multiply the income coefficient of the demand for food/feed for that region by a scalar. The scalar takes a value greater than one in the case of positive income shock and a value less than one with a negative shock. Mathematically, the market-clearing identity is now represented as,

$$\begin{aligned}
& I_{i,w}^{t-1} + \sum_{j=1}^J [S_{i,j}^t(P_{i,w}^t, P_{e,w}^t) + IM_{i,j}^t(P_{i,w}^t, P_{e,w}^t)] \\
&= \sum_{j=1}^J [D_{fi,j}^t(P_{i,w}^t, P_{e,w}^t, \delta_{i,j}^{f,t} GDPpc_j^t) + EX_{i,j}^t(P_{i,w}^t, P_{e,w}^t)] \quad (17) \\
&+ \sum_{j=1}^J D_{bi,j}^t(P_{i,w}^t, P_{e,w}^t) + I_{i,w}^t(P_{i,w}^t)
\end{aligned}$$

where,

$$D_{fi,j}^t(P_{i,w}^t, P_{e,w}^t, \delta_{i,j}^{f,t} GDPpc_j^t) = d_{i,j} + e_{i,j} \phi_j^t P_{i,w}^t + k_{i,j} \phi_j^t P_{e,w}^t + l_{i,j} \delta_{i,j}^{f,t} GDPpc_j^t$$

and  $\delta_{i,j}^{f,t}$  is a scalar quantity used to simulate a shock. Although the counterfactual scenario assumes no income growth, the income elasticity remains positive.

2. **Biofuel demand shock:** The biofuel shock is used to simulate a condition with no biofuel production. Mathematically, the market-clearing identity is now represented as,

$$\begin{aligned}
& I_{i,w}^{t-1} + \sum_{j=1}^J [S_{i,j}^t(P_{i,w}^t, P_{e,w}^t) + IM_{i,j}^t(P_{i,w}^t, P_{e,w}^t)] \\
& = \sum_{j=1}^J [D_{fi,j}^t(P_{i,w}^t, P_{e,w}^t, GDPpc_j^t) + EX_{i,j}^t(P_{i,w}^t, P_{e,w}^t)] \\
& \quad + \delta_{i,j}^{b,t} \sum_{j=1}^J D_{bi,j}^t(P_{i,w}^t) + I_{i,w}^t(P_{i,w}^t)
\end{aligned} \tag{18}$$

where  $\delta_{i,j}^{b,t}$  is a binary variable. When it is zero, it simulates a counterfactual scenario with no biofuel.

3. **Exchange rate shock:** To simulate changes in the exchange rate over time, we multiply all prices within a given region by the annual exchange rate. Mathematically, the market-clearing identity becomes,

$$\begin{aligned}
& I_{i,w}^{t-1} + \sum_{j=1}^J [S_{i,j}^t(\delta_{i,j}^{ex,t} P_{i,w}^t, \delta_{i,j}^{ex,t} P_{e,w}^t) + IM_{i,j}^t(\delta_{i,j}^{ex,t} P_{i,w}^t, \delta_{i,j}^{ex,t} P_{e,w}^t)] \\
& = \sum_{j=1}^J [D_{fi,j}^t(\delta_{i,j}^{ex,t} P_{i,w}^t, \delta_{i,j}^{ex,t} P_{e,w}^t, GDPpc_j^t) + EX_{i,j}^t(\delta_{i,j}^{ex,t} P_{i,w}^t, \delta_{i,j}^{ex,t} P_{e,w}^t)] \\
& \quad + \sum_{j=1}^J D_{bi,j}^t(\delta_{i,j}^{ex,t} P_{i,w}^t, \delta_{i,j}^{ex,t} P_{e,w}^t) + I_{i,w}^t(\delta_{i,j}^{ex,t} P_{i,w}^t)
\end{aligned} \tag{19}$$

where  $\delta_{i,j}^{ex,t}$  is a scalar quantity used to simulate an exchange rate shock that affects the domestic price in a region. Since in our model this is the only path through which prices can differ between regions, this work overestimates the exchange rate effect.

4. **Energy price shock:** To simulate changes in energy prices over time, we multiply energy prices within a given region by the annual change in energy prices. Mathematically, the market-clearing identity becomes,

$$I_{i,w}^{t-1} + \sum_{j=1}^J [S_{i,j}^t(P_{i,w}^t, \delta_{i,j}^{e,t} P_{e,w}^t) + IM_{i,j}^t(P_{i,w}^t, \delta_{i,j}^{e,t} P_{e,w}^t)] \tag{20}$$

$$\begin{aligned}
&= \sum_{j=1}^J [D_{fi,j}^t(P_{i,w}^t, \delta_{i,j}^{e,t} P_{e,w}^t, GDPpc_j^t) + EX_{i,j}^t(P_{i,w}^t, \delta_{i,j}^{e,t} P_{e,w}^t)] \\
&\quad + \sum_{j=1}^J D_{bi,j}^t(P_{i,w}^t, \delta_{i,j}^{e,t} P_{e,w}^t) + I_{i,w}^t(P_{i,w}^t)
\end{aligned}$$

where  $\delta_{i,j}^{e,t}$  is a scalar quantity used to simulate an energy price.

## 6.6. Numerical scenarios

Given the cumulative change in a variable with respect to the year 2001, we use the market-clearing condition to derive a counterfactual equilibrium world price for each crop for the various shocks for each year. We do so for four different alternative scenarios which either differ in the assumed range for elasticities used in calibration of supply and demand functions, or differ in the specification of the demand for food/feed (whether GDP per capita is explicitly represented in demand) or differ in parameters of the inventory demand function. Given the challenge of estimating a point estimate for the various elasticities, as well as the inventory parameters, we simulated these alternative scenarios to determine the robustness of our results.

The first scenario, which we henceforth refer to as the *baseline scenario*, is one in which we use the range of price and income elasticities reported in the literature, namely, that mentioned in the USDA's database of elasticities and in the FAPRI database. Under this scenario, the parameters for the inventory demand function are those that we estimate ourselves using the specification of Carter et al. [14]. As mentioned earlier, we perform 100 simulations of this scenario for the various shocks for each crop and for each time period but report the mean value of these outcomes.

In the second scenario, the *inelastic scenario*, we assume a narrower range for elasticities, which is on average more inelastic compared to the baseline scenario and follows Gardner [24]. This scenario further differs from the baseline in that we employ a demand specification that does not include income. The reason for excluding income is that some of the elasticities reported in the literature were based on models that did not include income.



**Table 5. Sources of data**

| <b>Data</b>  | <b>Source</b>  |
|--|--|
| Production, consumption and stocks in each region            | U.S. Department of Agriculture's Production, Supply and Distribution Data base (1)                   |
| Domestic price of grains, sugar and oilseeds                 | Food and Agriculture Organization of the United Nations (FAO) (2)                                    |
| World energy price   | International Monetary Fund Primary Commodity Prices (3)   |
| Biofuel production and consumption                           | Renewable Fuels Association (4)  |
| Exchange rates   | U.S. Federal Reserve Statistical Database (5)  |
| Price and income elasticities of supply and demand for crops | Food and Agricultural Policy Research Institute Elasticity Database and USDA elasticity database (6) |

1. <http://www.fas.usda.gov/psdonline>
2. <http://faostat.fao.org/>
3. <http://www.imf.org/external/np/res/commod/index.asp>
4. <http://www.ethanolrfa.org/industry/statistics/#E>
5. <http://www.federalreserve.gov/releases/G5A/>
6. <http://www.fapri.iastate.edu/tools/outlook.aspx>

Finally, to test the robustness of the inventory demand parameters, we simulate a fourth scenario using Carter et al.'s estimates for the inventory demand function as opposed to our own. Note that different from us, Carter et al. [14] estimate the inventory demand based on U.S. data for 2006 through 2008, while we use world data for 2001 through 2008.

### *6.7. Sources of data*

The various data sources are shown in Table 5. Data on production, consumption, beginning and ending stocks, imports, and exports for each region are obtained from the U.S. Department of Agriculture's Production, Supply and Distribution database. Data on crop prices within each region are obtained from the FAO database. A key set of parameters in simulation models is the elasticities of crop supply and crop demand. Our specification of supply and demand requires information on elasticities of supply and demand with respect to own-price elasticities of supply and demand with respect to energy price and the income elasticity of demand. The range of elasticities contained in FAPRI database and in the literature cited by the USDA database is shown in Table 3.

## 7. Results

We report two different price changes:

1. Reduction of commodity price if key variables would have stayed at their 2001 levels,  $\Delta P_{t,i}$ . Technically, it is the percentage difference between the actual price in a given year and the counter-factual price for the same year, and
2. The increase of the commodity price attributed to a change in one of the variables (income, biofuel mandate, exchange rate, energy prices) between 2001 and the specific year,  $\Delta P_{t/2001,i}$ , where  $i \in \{\text{biofuel, income growth, energy prices, exchange rate}\}$ . Technically, it is the percentage difference between counter-factual price for a given year and the price in 2001.

The simulations compute  $\Delta P_{t,i}$ . We then compute  $\Delta P_{t/2001,i}$  as follows: let  $\Delta P_t^a$  denote the total percentage price change between the year  $t$  and year 2001; then,

$$\Delta P_{t/2001,i} = \Delta P_{t,i}(1 + \Delta P_t^a)/\Delta P_t^a, \quad (21)$$

Total change in price from year  $t$  to year 2001 that is explained by our model equals the sum of  $\Delta P_{t/2001,i}$  over all the shocks. The figures depict  $\Delta P_{t,i}$  – namely, the food commodity price reduction attributed to a shock that eliminates one of the factors that caused prices to change after 2001, whereas the tables show  $\Delta P_{t/2001,i}$  – namely, the increase in commodity prices from 2001 attributed to one of the factors that caused prices to change after 2001. In both cases we report the mean outcome of 100 simulations, where for each run we draw a number from a range of plausible values (for price, income, and supply elasticities) and compute the counterfactual outcome. When presenting prices for different crops, we distinguish between two different specifications: one with inventory demand function and another without inventory demand. For each crop, we show the impact of these shocks one at a time.

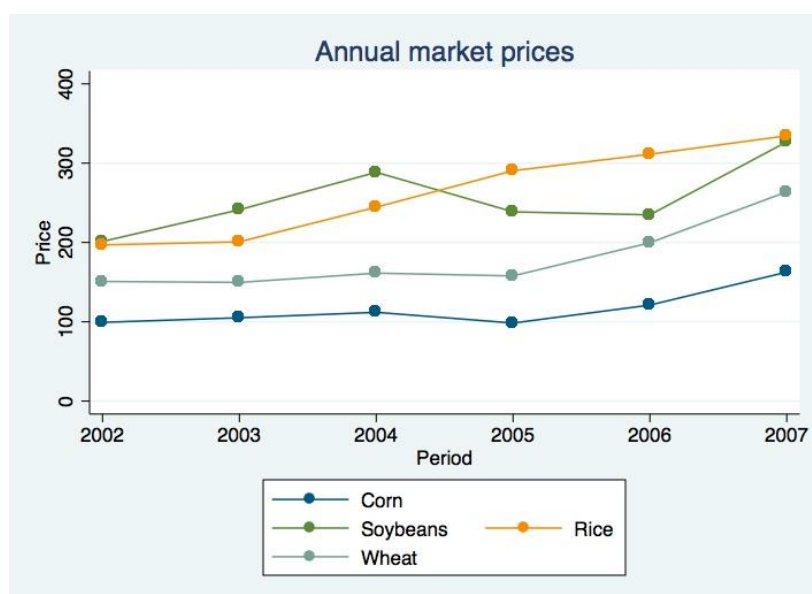
The analysis includes five simulated scenarios for each of the five crops, namely, corn, soybeans, rapeseed, rice, and wheat. The baseline scenario's outcome is contrasted with alternative specifications to evaluate robustness of the relative and absolute value of the numerous shocks. The alternative scenarios illustrate the robustness of the results presented with respect to relative impact, but the absolute impact usually becomes larger as elasticities become smaller. Some but not all scenarios include an income term in the demand specification

for food and feed. Introducing an income term reduces the biofuel impact. While for the first four scenarios we estimated an inventory demand function, for the fifth scenario, we borrowed the parameters from Carter et al. [14]. The estimated parameters suggest, on average, more elastic inventory demand, and thus less fluctuation in prices. We conclude this section by qualitatively discussing the role of trade policy and speculation and role of inventory management for limiting the impact of future shocks.

We begin this section by presenting the results of the baseline scenario.

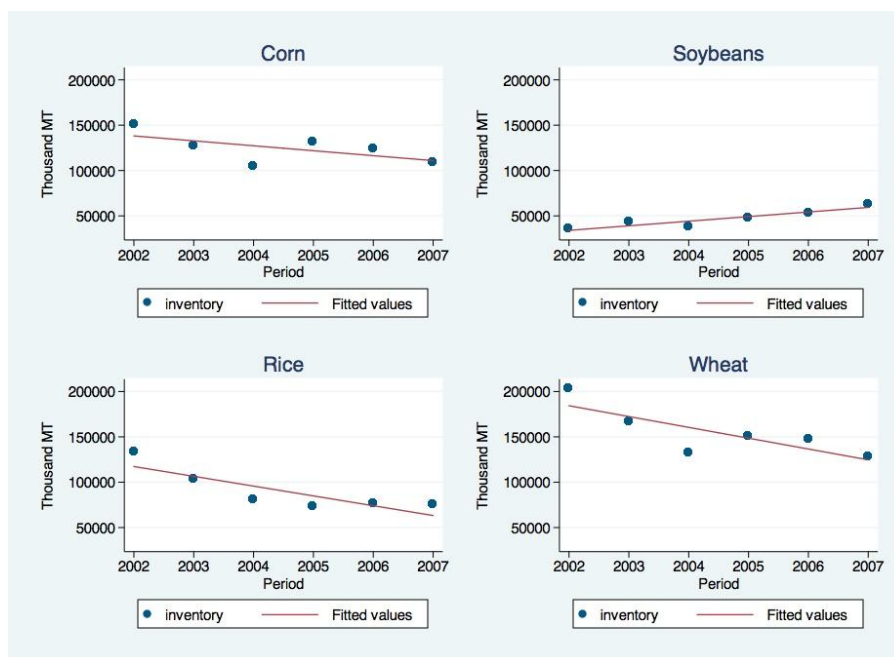
### 7.1. The baseline scenario

The observed prices for the different crops are shown in Figure 18. A clear upward trend, on average, emerges for all crops, albeit some prices increase more than others. Whereas the price of corn and soybeans increased from 2002 to 2006 by about 63%, the price of wheat increased by more than 74%. Furthermore, while some crops like rice and wheat experienced an upward trend throughout the period, others such as soybeans declined in 2005 and 2006 only to increase by 39% in 2007.

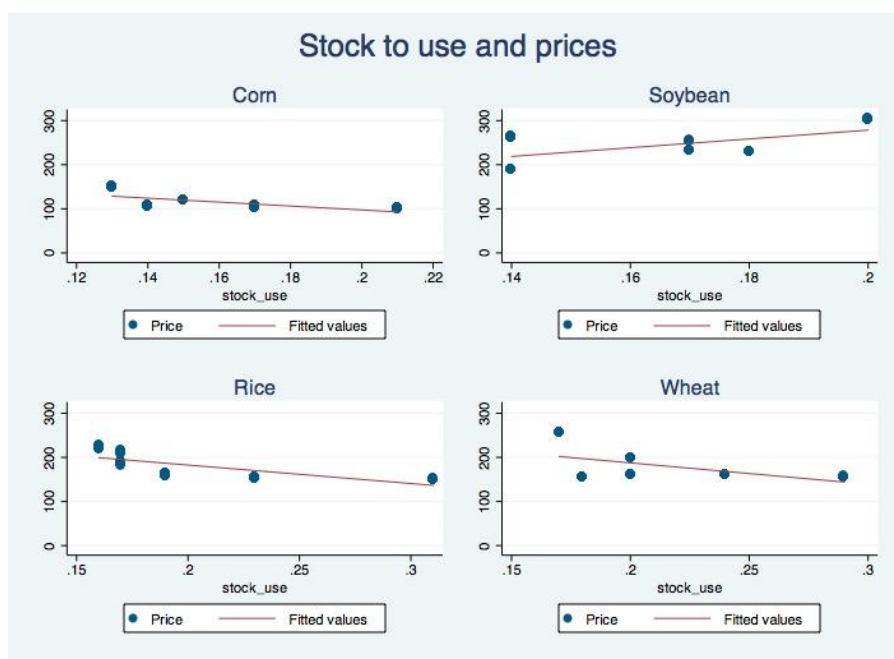


**Figure 18. Average (actual) annual prices (in US 2005 \$ per tonne)**

Inventory theory predicts that prices decline when inventory accumulates, and vice versa. The data confirm these predictions, except for soybeans, and show similar trends for stock-to-use ratio (see figures 19 and 20). If, however, we drop 2007 (a year where soybean prices spiked), then such a pattern is also observed for soybeans.



**Figure 19. Inventory trends for various crops**



**Figure 20. Crop prices and the stock-to-use ratio**

Inventory serves as a buffer and affects prices as long as inventory levels are sufficiently large. However, as these levels become small, prices become more volatile and sensitive to the numerous specific factors affecting crop prices. We observe this relation, and less fluctuation is observed if inventory demand is explicitly added to the analysis. The aggregate demand curve becomes much more elastic for large inventory levels, and thus predicts less price volatility.

The annual increase in corn and soybean prices is largest toward the end of the sample period

(i.e., between 2006 and 2007). One explanation for the observed price fluctuation in corn and soybeans is that consumption of corn for biofuel became significant around 2006, when the federal government began implementing biofuel mandates. Although biofuel subsidies have been in effect for several decades, mandates are the main cause for the recent increase in biofuel production. Furthermore, land allocated to corn replaces soybean land, resulting in higher soybean prices (not modeled explicitly in the report, because we do not have data on land use). This complements the upward pressure on soybean prices attributed to biodiesel production. On the other hand, economic growth results in structural changes to demand in countries like China, where increased demand for feed led to larger demand for soybeans [66] (considerable growth (around 20%) between 2000 and 2008 was also observed for pork).

Because we assume rice and wheat are not utilized for biofuels in any significant quantities, and since land growing rice and wheat do not generally compete with corn, sugarcane and oilseeds, we conclude that the prices of rice and wheat are not influenced by biofuels. However, a general equilibrium framework, in contrast to the multi-market framework presented here, may identify indirect linkages between biofuel production and rice and wheat [47].

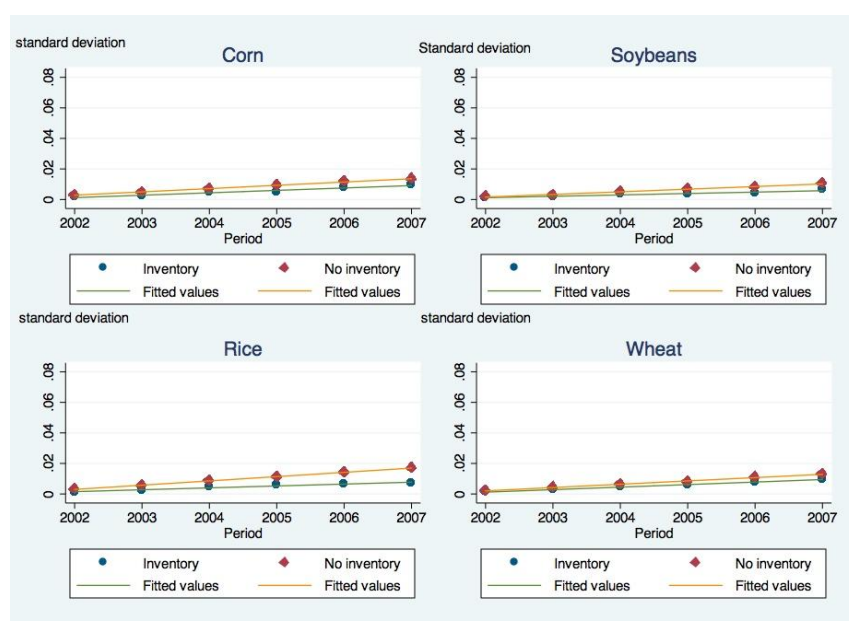
When the market for storage is excluded, higher price fluctuations are documented (figures 21 and Table 6). We plotted the standard deviation of prices for five crops for a represented shock, and show that the shock caused prices to fluctuate more when inventory is not modeled explicitly. This picture emerges for all shocks. Inventory specification matters.

Introducing inventory demand alters outcomes. Then, because we do observe inventories and introducing inventory to the numerical model makes a difference, we focus below on simulations with inventory demand.

**Table 6. Contribution of various factors on increased price of selected food commodities**

(% price increase from counterfactual scenario in a given year)

|                                     | With inventory |       |       | Without inventory |       |       |
|-------------------------------------|----------------|-------|-------|-------------------|-------|-------|
|                                     | Year           |       |       | Year              |       |       |
| Crop                                | 2005           | 2006  | 2007  | 2005              | 2006  | 2007  |
| Biofuel shock                       |                |       |       |                   |       |       |
| Corn                                | 4.4%           | 6.8%  | 9.8%  | 5.5%              | 7.4%  | 9.8%  |
| Soybean                             | 1.0%           | 1.8%  | 3.4%  | 1.5%              | 2.6%  | 4.1%  |
| Rice                                | 0.0%           | 0.0%  | 0.0%  | 0.0%              | 0.0%  | 0.0%  |
| Wheat                               | 0.0%           | 0.0%  | 0.0%  | 0.0%              | 0.0%  | 0.0%  |
| Income shock                        |                |       |       |                   |       |       |
| Corn                                | 7.9%           | 12.2% | 15.3% | 12.4%             | 16.7% | 19.5% |
| Soybean                             | 6.3%           | 8.9%  | 14.7% | 12.1%             | 15.6% | 22.1% |
| Rice                                | 11.6%          | 13.5% | 16.1% | 20.9%             | 27.9% | 35.1% |
| Wheat                               | 11.1%          | 16.0% | 21.2% | 15.1%             | 21.4% | 27.7% |
| Exchange rate shock                 |                |       |       |                   |       |       |
| Corn                                | 3.5%           | 5.0%  | 7.6%  | 4.6%              | 6.2%  | 9.4%  |
| Soybean                             | 1.0%           | 2.4%  | 5.3%  | 1.4%              | 3.8%  | 7.9%  |
| Rice                                | 3.3%           | 4.0%  | 6.5%  | 6.7%              | 8.3%  | 14.4% |
| Wheat                               | 6.6%           | 7.3%  | 11.0% | 8.1%              | 8.9%  | 13.1% |
| Energy price shock                  |                |       |       |                   |       |       |
| Corn                                | 2.2%           | 2.9%  | 2.9%  | 3.3%              | 3.6%  | 3.6%  |
| Soybean                             | 1.9%           | 2.4%  | 2.4%  | 3.6%              | 4.0%  | 4.0%  |
| Rice                                | 3.0%           | 3.0%  | 3.0%  | 2.4%              | 2.6%  | 2.6%  |
| Wheat                               | 2.8%           | 3.1%  | 3.1%  | 3.6%              | 4.0%  | 4.0%  |
| Aggregate effect of all four shocks |                |       |       |                   |       |       |
| Corn                                | 18%            | 27%   | 36%   | 26%               | 34%   | 42%   |
| Soybean                             | 10%            | 15%   | 26%   | 19%               | 26%   | 38%   |
| Rice                                | 18%            | 20%   | 26%   | 30%               | 39%   | 52%   |
| Wheat                               | 20%            | 26%   | 35%   | 27%               | 34%   | 45%   |



**Figure 21. The implication of demand and supply shocks on prices with and without inventory**

## 7.2. Decomposing the change in crop prices

Decomposing changes in crop prices involves numerous factors, some affecting demand whereas some affect supply. We limit our analysis to four such factors; namely, biofuel, income, exchange rate, and energy prices. Other factors that need to be considered, but are outside the scope of this work, are productivity shocks, trade policy, and speculation. We report below the change in prices (due to the shocks) in a certain year compared to actual or observed prices in that same year.

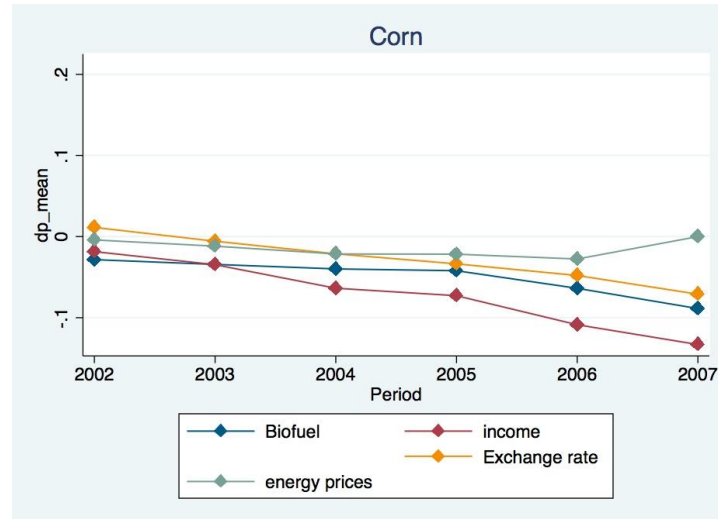
### 7.2.1. Corn

The results of four different shocks, applied one at a time for the period 2002-2007, are depicted in Figure 22. In particular, the figure presents the decline in the price of corn, if demand for corn did not grow because of the GNP growth, biofuel was not mandated, energy prices did not increase, and the US\$ was not devalue. Note that the results in table 6, and different from the figures, project the inverse relationship, the increase in food commodity price because of economic growth, introduction of biofuel, higher energy prices and the depreciation of the US\$. Throughout the text, as mentioned above, the figures and the tables present the results of our simulated scenarios from two vantage points. The table shows the price increase because of a change in factor  $i$  (i.e.,  $\Delta P_{t/2001,i}$ ), whereas the figures represent the price reduction if the observed change in factor  $i$  would not have happened (i.e.,  $\Delta P_{t,i}$ ) – equation (21) shows the relation between  $\Delta P_{t/2001,i}$  and  $\Delta P_{t,i}$ .

Two dominant factors affect corn prices: The introduction of biofuels and economic growth (see Figure 22 and Table 6). Whereas in the absence of an increase in demand for corn, prices would have been 15% lower in 2007, prices would have been 10% lower without the increase in biofuel production (Table 6). If we ignore the fact that the co-product of corn ethanol production, namely, distillers grains, is a substitute for corn, then biofuels appropriate a larger quantity of corn that is traditionally consumed as feed and, as a result, become responsible for about 12% of the price increase in 2007. The single largest use of corn is feed grain for animals, which is used for meat and dairy. Furthermore, meat consumption tends to increase with income, resulting in higher demand for corn in emerging economies. As per FAO statistics, in China, which witnessed average growth rate of 8.5% between 1990 and 2003, per capita meat consumption increased 150% from approximately 20 kg per person per year in the year 1985, to approximately 50 kg per person per year by the year 2000. Furthermore, increase in per

capita meat consumption should be expected not only in China but worldwide due to economic growth.

The depreciation of the US\$ resulted in corn prices increasing by 7%. The US\$ depreciated relative to major currencies around the world, suggesting prices in local currency around the world declined all else equal, shifting demand up and to the left.



**Figure 22. Impact of shocks on corn prices (simulated)**

Finally, introducing inventory demand to corn markets affects the price dynamics of corn prices and lowers price volatility. Using Analysis of Variance techniques (ANOVA), we tested the hypothesis that introducing an inventory demand function does not affect corn prices. We reject this hypothesis at a 1% significant level and conclude that the path of corn prices between 2002 and 2007, when an inventory demand function is included, is different than the path observed if, instead, such a function is not included (i.e., the between p-value is less than 1%). Moreover, the variance in prices is larger when inventory demand is not introduced. We conclude that not introducing demand for inventory overestimates the price fluctuation of corn (Figure 21).

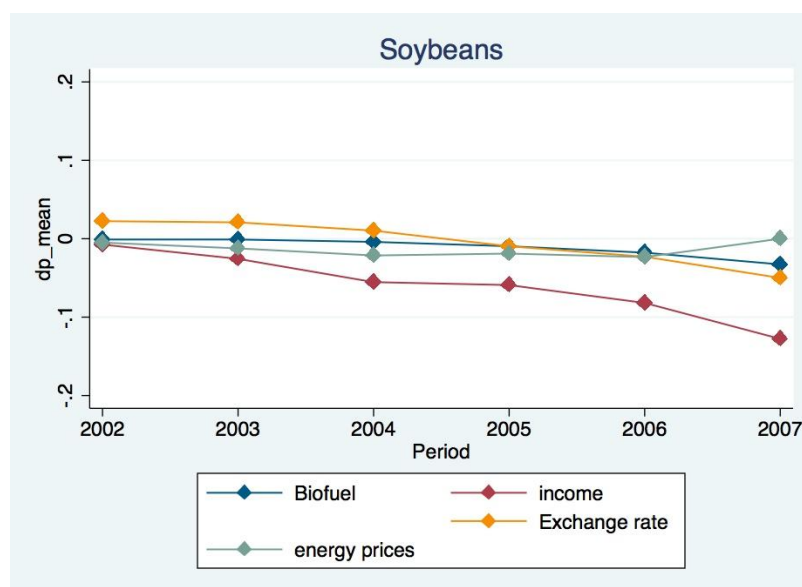
Using equation (21), we find that biofuels contributed 19.8% to the increase in corn price in 2007 relative to 2001, income shock contributed 29.6%, exchange rate shocks contributed 15.81%, and energy shocks contributed at least 10.8%.

### 7.2.2. Soybeans

**Soybean prices are affected primarily by the increase in demand due to economic growth.** The increase in income that led to increased demand, contributed more than 15% to



the soybean price spike in 2007 (Table 6). The impact of biofuel is smaller than that for corn and is about 4%. Similar to corn, the single largest use of soybean is feed for livestock and poultry, which has witnessed rapid growth in demand due to economic growth. The reduction of soybean prices, when key factors would have stayed at their 2001 levels, is shown in Figure 23.



**Figure 23. Impact of shocks on soy prices (simulated)**

The relation between inventory and soybean prices is similar to the one identified with respect to corn prices (with the exception of 2007). The analysis suggests that inventory demand is statistically different from a model with no inventory demand at a 1% significant level (i.e., the between p-value is 1%).

Using equation (21), we find that biofuels contributed 7.4% to the increase in soybean price in 2007 relative to 2001, income shocks contributed 28.6%, exchange rate shocks contributed 11.2%, and energy shocks contributed at least 10.0%.

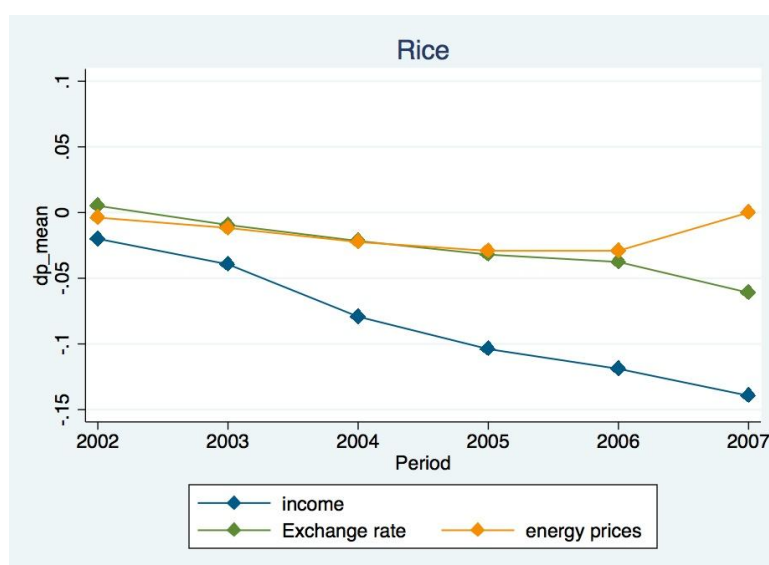
### 7.2.3. Rice

In our model, rice production and consumption are not affected by biofuel. Therefore, we do not model a biofuel shock but concentrate on the income, exchange rate, and energy prices shocks (Figure 24).

Rice prices are affected by the income shock, which contributes 14% to the price increase in 2007 (figure 24). The price dynamics can be explained by the fact that rice is mostly consumed in the fastest growing economies in the world such as China, India, Indonesia, and several

countries in South and Southeast Asia. China, India, and Indonesia account for 36.8%, 23.2%, and 10.1% of world rice consumption, respectively.

Rice is the dominant staple food crop in developing countries, particularly for the humid tropics across the globe. Almost 90% of rice is produced and consumed in Asia, and 96% in developing countries. Most of the growth in production originated from technological progress in the irrigated and favorable rainfed ecosystems.



**Figure 24. Impact of shocks on rice prices (simulated)**

Some argue that rice is an inferior good, implying that the specification under the baseline scenario is flawed—the income elasticity should be negative not positive. We address this in the inelastic scenario where no income effect was assumed.

The rate of growth in rice consumption has started slowing down because of urbanization and increases in per capita income leading to diversification of the diet,<sup>12</sup> high levels of rice consumption already reached in many countries, and progress in reducing population growth. But, the growth in rice supply has also slowed down because of the yield-approaching economic maximum for the irrigated ecosystem, decline in relative profitability of rice cultivation, increasing concerns regarding environmental protection, and limited progress in developing improved technologies for the unfavorable ecosystems. Trade policy also had its share (e.g., India in 2008).

Two contrasting developments may substantially affect the rice economy in the future. First, the prosperous rice-growing countries may increasingly find it difficult to sustain producers'

<sup>12</sup><http://www.commodityonline.com/news/Why-global-rice-production-is-plunging-13800-2-1.html> and <http://beta.irri.org/index.php/Home/Welcome/Frontpage.html>

interest in rice farming.

The move towards free trade in agricultural production begun with the Uruguay Round of General Agreement on Tariffs and Trade (GATT), will affect the sustainability of rice farming in these countries. There will be economic incentives for the movement of land, water, and labor out of rice to other economic activities. Second, the potential for increased productivity for the irrigated ecosystem, created by the dramatic technological breakthrough in genetic enhancement of seeds that initiated the green revolution, has almost been exploited, while improved varieties for the unfavorable ecosystems expected from the ongoing gene revolution are still on the horizon. As such, the worldwide situation with genetically modified (GM)rice is basically development as opposed to distribution—the problem is not regulatory constraints on distribution but lack of varieties with required traits.<sup>13</sup> Currently, several dozen varieties of GM rice are underdeveloped or are undergoing field testing. Between 1982 and 1997, 160 patents were granted or pending. In 2001, the mapping of the rice genome was completed, spurring further GM development.

In the absence of exchange rate shock, rice price would have been 6% lower from the actual price observed in 2007 (Figure 24). Although China is the largest rice producer (its share in global rice production is approximately 33%), and its currency only marginally fluctuates relative to the US\$, many other countries that produce rice saw their currency strengthen relative to the US\$.

In response to rising food prices, different countries adopted a range of different short-term measures. An FAO report [17] classifies these measures into three main groups, namely, trade-oriented policies such as reducing import tariffs and export restrictions, consumer-oriented policies such as food subsidies price controls and policies reducing inventory, and thirdly, producer-oriented policies such as input subsidies. Based on information obtained from 81 countries, they report the two most widely applied measures are reduction of tariffs, as reported by 43 countries, and releasing grain from public stocks, as reported by 35 countries. While tariff reductions are easy to implement, the efficacy of the latter policy depends on the level of reserves. In an attempt to shore up domestic supply, several major grain-exporting nations also imposed export restrictions and in some cases banned them altogether in response to the food price inflation. Examples of nations with such restrictions include Argentina, Cambodia, China, Egypt, India, Kazakhstan, Pakistan, Russia, Ukraine, and Vietnam. However, world prices escalated as a result of such restrictions. The

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<sup>13</sup><http://beta.irri.org/index.php/Home/Welcome/Frontpage.html>

most severe impact of export restrictions has been on world rice market, which is traditionally thin in trade. In our report, the impact of trade policy restrictions are indirectly captured through exchange rate shocks, and magnifies the impact of the exchange rate on rice prices.

Energy prices contributed about 3% to the price increase. The spike in crude oil and the impact it had on energy prices caused prices to increase albeit only by a few percentage points.

Explicit consideration of storage demand has a statistically significant effect on model predictions for rice. Similar to corn and soybeans, we reject the hypothesis that the dynamic price path of rice with an inventory demand function is not different from a model without an inventory demand function.

Using equation (21), we find that income shock contributed 29.6% to the increase in rice price in 2007 relative to 2001, exchange rate shocks contributed 13.0%, and energy shocks contributed at least 6.7%.

#### *7.2.4. Wheat*

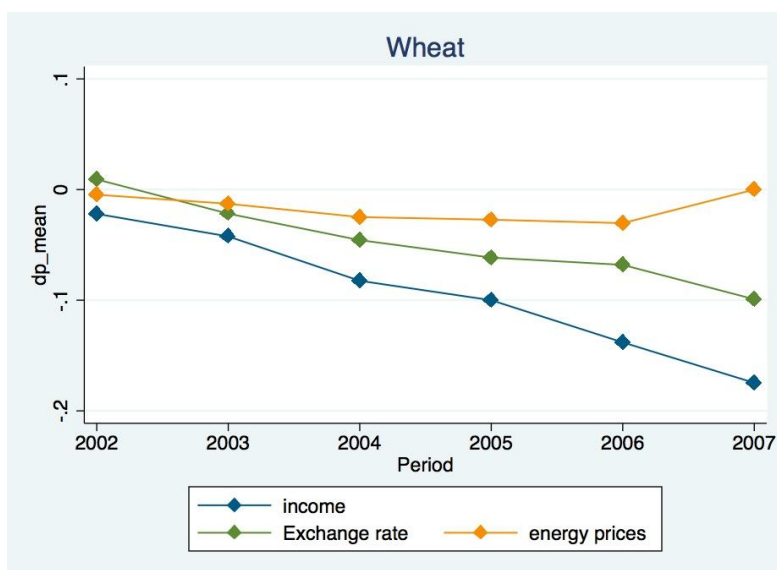
**The main contributor to the increase in the price of wheat is the demand shock.** In 2007 world production of wheat was 607 million tons, making it the third most-produced cereal after maize (784 million tons) and rice (651 million tons). Wheat also supplies much of the world's dietary protein and food supply, with China consuming in 2007 nearly 30% of global wheat consumption. Therefore, the impact of an income shock dominates the other effects (figure 25). It contributed more than 21% to the increase in wheat prices during 2007 (Table 6 and Figure 25).

The depreciation of the US\$ resulted in wheat prices being 10% higher. Finally, and similar to other crops, we reject the hypothesis that price dynamics does not depend on inventory at a 1% significant level.

Using equation (21), we find that income shock contributed 34.4% to the increase in wheat price in 2007 relative to 2001, exchange rate shocks contributed 19.5%, and energy shocks contributed at least 8.6%.

As pointed out above, although biofuel is an important factor contributing to the price spike, demand growth due to income and probably population growth is the main factor. Other scholars have also arrived at the conclusion that demand growth is a key factor affecting food prices. Employing a partial equilibrium framework, Subramanian and Deaton [63] argued that

demand shifters played a crucial role in explaining food prices, while Alston et al. [4] commented that in the absence of an increase in productivity food prices should rise.



**Figure 25. Impact of shocks on wheat prices (simulated)**

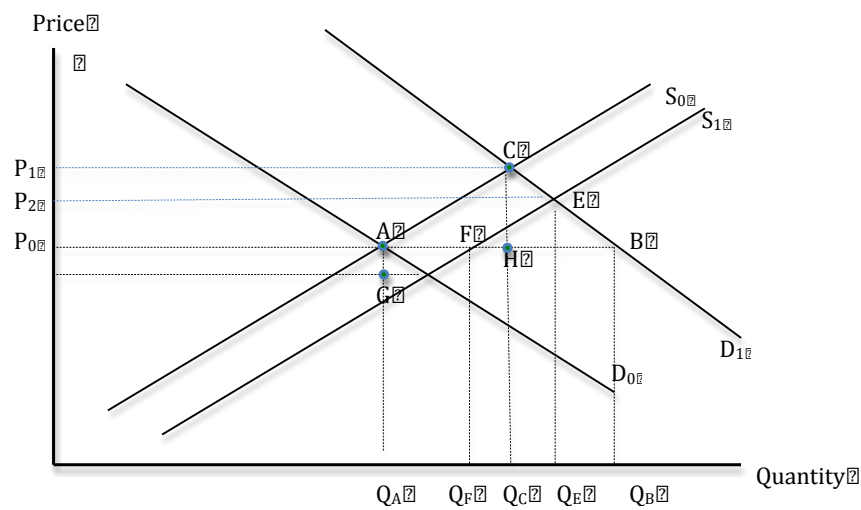
The study by Baffes and Hanjotis [7] suggests that the role of demand is not as prominent, because low level of growth in consumption during the investigated period – especially of wheat and rice. However, changes in consumption are different than changes in demand. Growth in income and population, coupled with high-income elasticity, contributed to the increase in demand. Yet, production did not grow much, especially in the case of wheat and rice. So the growth in supply was modest, leading to a modest increase in consumption but a large increase in price. The rate of growth in consumption of soybean and corn was higher than wheat and rice, reflecting larger productivity gains (Sexton et al. 2009). But as income grew, demand for meat and thus demand for feed grew as well, resulting in an increase in prices and reduction of inventories. Thus, economic growth is an important contributor to the rise in food commodity prices. The study by Baffes and Hanjotis also emphasizes the role of commodities by financial investors in 2007/08 food commodity price spike, which we did not investigate.

The baseline model explains the fluctuation in prices. It captures the effect of biofuel, income growth, energy prices, and exchange rate on food commodity prices. The report does not introduce population growth, speculation, and trade policy, as well as supply factors such as productivity growth and weather shocks to the analysis. Having said that, we next calculate how much of the total price change the simulation explains, correcting for yield effects reported in the literature [4]. Supply shift due to yield increase reduced upward pressure exerted by the increase in demand. Thus, we use the slope of the supply function, and assume

annual yield growth of 1.5% shifts supply to the right, and compute  $\Delta P_{yield}$ , i.e., line segment  $GA$  in Figure 26. Then, the amount explained by our model is simply

$$\text{amount explained} = \frac{\Delta P_t}{\Delta P_t^a + |\Delta P_{yield}|}$$

where  $\Delta P_t = \sum_i \Delta P_{t,i}$  is the sum of the price change explained by the different shocks ( $i \in \{\text{biofuel, income growth, energy prices, exchange rate}\}$ ), and recall that  $\Delta P_t^a$  is the price change observed between period  $t$  and 2001, i.e., line segment  $HC$  in Figure 26. Table 7 shows the total explained price increase with respect to 2001.



**Figure 26. Total explained price change**

The amount of the price fluctuation explained by our model is different for different crops, in part because the omitted factors affect some crops more than others. For instance, we did not add trade policy shocks, which affected rice, and we do not have weather shocks, which adversely affected wheat.

**Table 7. Total percent price change in 2007 explained by numerical model**

| % explained | With respect to 2001 |
|-------------|----------------------|
| Corn        | 70%                  |
| Soybean     | 55%                  |
| Rice        | 47%                  |
| Wheat       | 54%                  |

### 7.3. Sensitivity analysis

Because the empirical estimation of the demand and supply parameters, as well as the demand

for inventory, are challenging but are key step to accurately measuring the factors causing the food inflation of 2007-08, two additional scenarios were numerically simulated to further check the robustness of our conclusion.

### 7.3.1. *Inelastic scenario*

Key parameters in our analysis and in simulation-based models in general are the elasticities, which are used to calibrate the demand and supply curves. The alternative specification, denoted the *inelastic scenario*, assumes lower elasticities. The elasticities used in the baseline scenario were obtained from well-known and widely used sources such as the FAPRI elasticity database and the USDA elasticity database.<sup>14</sup> However, according to several other researchers, the elasticities of supply and demand for agriculture are more inelastic than those reported in the above databases (For instance, see Gardner [24] for a discussion of supply and demand elasticities for agricultural commodities). In order that the elasticities are on average lower than those in the baseline scenario and also conservative, we chose own-price supply elasticities in the range 0.2 to 0.3 and own- price demand elasticities in the range -0.3 to -0.2. Employing these elasticities, we find that the main qualitative conclusions regarding the importance of the different shocks from the baseline scenario hold.<sup>15</sup>

Comparing the baseline scenario to the inelastic scenario results in the price changes summarized in Table 8. This comparison emphasizes the importance of obtaining good elasticity estimates. Elasticity matters, and the more inelastic scenario result in a larger impact.

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<sup>14</sup><http://www.ers.usda.gov/Data/InternationalFoodDemand/>

<sup>15</sup>To this end, using world data on four major crops, namely, corn, soybeans, wheat, and rice from 1960 to 2007, Roberts and Schlenker estimate that short-term, own-price elasticity of supply and demand for calories from these crops is less than 0.15 and greater than -0.1, respectively [58].

**Table 8. Comparison of results between main and sensitivity analysis** (% change as compared to the counterfactual scenario in 2007)

| <b>Shock</b>         | <b>Crop</b>    | <b>Main Analysis</b> | <b>Sensitivity analysis</b> |
|----------------------|----------------|----------------------|-----------------------------|
| <b>Biofuel</b>       | <b>Corn</b>    | 9.8%                 | 12.7%                       |
|                      | <b>Soybean</b> | 3.4%                 | 3.7%                        |
| <b>Income growth</b> | <b>Corn</b>    | 15.3%                | 20.3%                       |
|                      | <b>Soybean</b> | 14.7%                | 16.0%                       |
|                      | <b>Rice</b>    | 16.1%                | 17.2%                       |
|                      | <b>Wheat</b>   | 21.1%                | 25.8%                       |

### 7.3.2. Price effect of shocks using inventory specification of Carter et al. [14].

Finally, we simulate the model using the inventory demand parameters estimated in Carter et al. [14]. Results confirm the conclusions derived for the baseline scenario. The price effect now is marginally smaller for all shocks. This is because the estimates of the parameters of the inventory demand employed in the elastic scenario imply an inventory demand function that is on average more elastic compared to that suggested by parameters estimated by Carter et al.

## 8. Conclusion

This report has focused on four major factors widely agreed to be responsible for food commodity price increases – economic growth, biofuel expansion, exchange rate fluctuations, and energy price change. The study also captures the effect of inventory adjustments. Incorporating an empirically estimated inventory demand function into the market-clearing condition shows that the impact of inventory on prices increases as the level of inventory diminishes. We find that in the absence of shocks attributable to the four factors mentioned above, in 2007 the prices of corn, soybean, rapeseed, rice, and wheat would have been 26% to 36% lower than the observed prices in that year. On the other hand, if inventory demand were to be ignored, in 2007 the prices would have been 38% to 52% lower than the observed prices in that year. Abstracting from considerations of inventory responses leads to predictions of larger price changes.



Because key parameters in our analysis are the elasticities which are used to calibrate the demand and supply curves, we performed several sensitivity analyses on these values. In these alternative scenarios we introduced more inelastic curves and compared our results to those obtained if, instead of our estimated inventory parameters, we used the inventory parameters from Carter et al. [14]. We conclude that although the percentage changes vary between scenarios, the main conclusion that inventory matters does not change. The relative magnitude of the various shocks also does not change.

From a policy standpoint, the food crisis emphasizes both the importance of a proactive inventory management policy, and the need for mechanisms that either compensate the poor when prices rise to abnormally high levels or more directly mitigate spikes in food prices. Such mechanisms may include biofuel mandates that adjust automatically to the situation in food markets, as well as inventory management policies. Expanding agricultural supply through investment in research and development, and introducing policies that would allow more effective utilization of existing technologies as well as investment in outreach and infrastructure that will enhance productivity, also reduce the likelihood of a food price spike.

One limitation of this paper is that some important crop-specific factors, such as weather and productivity shocks (especially for wheat) and trade policies (especially for rice), are not considered. Another factor not considered in this report is speculation. The reasons for exclusion of these factors are data as well as model limitations. Another limitation is that we looked at each market separately, rather than in an integrated manner. No cross-price elasticities were introduced, which may lead us to underestimate the impact of the different factors on prices.

Although our conclusions are robust to a broad range of assumptions about the price elasticity of supply and demand for crops and parameters of the inventory demand function, an important area of future work is the empirical estimation of these parameters. Identifying correctly the inventory demand curve is a challenge, and is a key step to accurately measuring the factors causing the food inflation of 2007-08. In future work we plan to further investigate these relationships, and to introduce cross- price elasticities. Moreover, the study does not cover the 2008-2010 period, which was characterized by strong commodity price volatility. Thus, a further study is imperative to generate more policy insights by extending this study, incorporating the factors excluded here and also covering the 2008-2010 period.

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